The sustainable freight railway: Designing the freight vehicle – track system for higher delivered tonnage with improved availability at reduced cost

SUSTRAIL

Grant Agreement n°: 265740 FP7 - THEME [SST.2010.5.2-2.]
Project Start Date: 2011-06-01
Duration: 48 months

D5.6: Final Business Case synthesis report

Due date of deliverable: 28/02/2015

Actual submission date: 19/05/2015

Work Package Number:	WP5
Dissemination Level:	PU
Status:	Draft
Leader of this deliverable:	University of Leeds, UNILEEDS
Prepared by:	John Nellthorp (UNILEEDS) Phillip Wheat (UNILEEDS) Dan Johnson (UNILEEDS) Matti Rantatalo (LTU) Stephen Famurewa (LTU) Kevin Blacktop (NR) Juan de Dios Sanz Bobi (UPM) Kiril Karagyozov (VTU) Todor Razmov (VTU) Anna Dzhaleva (VTU) Mirena Todorova (VTU)
Verified by:	Kevin Blacktop (NR)

Dissemination Level	
PU	Public
PP	Restricted to other programme participants (including the Commission Services)
RE	Restricted to a group specified by the consortium (including the Commission Services)
CO	Confidential, only for members of the consortium (including the Commission Services)

Document History			
Version	**Date**	**Author/s**	**Description**
0.1	06/05/2015	John Nellthorp	Outline
0.2	12/05/2015	Phillip Wheat, Dan Johnson	Track Access Charges and Implementation sections
0.3	14/05/2015	John Nellthorp, Matti Rantatalo, Stephen Famurewa	Financial Analysis, Cost-Benefit Analysis, User Benefit and Environmental Benefit Analysis, LCC&RAMS analysis
1.0	14/05/2015	John Nellthorp	Conclusions, Executive Summary
1.1	15/05/2015	John Nellthorp	Referencing
1.2,1.3	19/05/2015	John Nellthorp	Amendments in response to QA reviewer's comments

Disclaimer

The information in this document is provided as is and no guarantee or warranty is given that the information is fit for any particular purpose. The user thereof uses the information at its sole risk and liability.

The document reflects only the author's views and the Community is not liable for any use that may be made of the information contained therein.

Table of contents

EXECUTIVE SUMMARY **5**

1. INTRODUCTION **8**

1.1 THE SUSTRAIL INNOVATIONS 8
1.2 THE ROLE OF THE BUSINESS CASE IN SUSTRAIL 9
1.3 SCOPE OF THIS DELIVERABLE 10

2. RESEARCH LEADING TO THE BUSINESS CASE **11**

2.1 BUSINESS CASE FRAMEWORK AND METHOD 11
2.2 THE PRIORITISATION OF DUTY REQUIREMENTS 13
2.3 THE SELECTION OF VEHICLE AND TRACK INNOVATIONS 14
2.3.1 Selection of vehicle innovations *14*
2.3.2 Selection of track innovations *16*
2.4 LCC AND RAMS MODELLING 16
2.5 AGGREGATION AND THE IMPACTS OF SUSTRAIL INNOVATIONS 18
2.6 USER AND ENVIRONMENTAL BENEFITS 19
2.7 TRACK ACCESS CHARGES RESEARCH 20
2.7.1 Strategy for access charge differentiation in the SUSTRAIL Business Case *21*
2.8 IMPLEMENTATION RESEARCH 22
2.9 THE INTERIM BUSINESS CASE 23

3. THE FINANCIAL BUSINESS CASE **24**

3.1 OUTLINE OF THE ANALYSIS 24
3.2 RESULTS FOR SUSTRAIL VEHICLE 24
3.2.1 Impact on the Infrastructure Manager *24*
3.2.2 Impact on the Freight Operators *25*
3.2.3 Impact on End Users *26*
3.3 RESULTS FOR SUSTRAIL VEHICLE AND TRACK 27
3.3.1 Impact on the Infrastructure Manager *27*
3.3.2 Impact on the Freight Operators *28*
3.3.3 Impact on End Users *29*
3.4 RESULTS FOR SUSTRAIL VEHICLE AND TRACK OPERATING AT HIGHER SPEED 30
3.4.1 Impact on the Infrastructure Manager *30*
3.4.2 Impact on the Freight Operators *30*
3.4.3 Impact on End Users *31*

4. THE SOCIO-ECONOMIC BUSINESS CASE **32**

4.1 OUTLINE OF THE ANALYSIS 32
4.2 RESULTS 32
4.3 RESULTS 33

5. IMPLEMENTATION OF THE SUSTRAIL INNOVATIONS **35**

5.1 TECHNICAL IMPLEMENTATION 35
5.2 HUMAN FACTOR ISSUES 37

6. CONCLUSIONS **40**

7. REFERENCES **42**

List of Figures

FIGURE 1.1: FINITE ELEMENT ANALYSIS OF THE LIGHTWEIGHT SUSTRAIL VEHICLE BODY STRUCTURE 8
FIGURE 1.2: ROLE OF WP5 AS AN ITERATIVE FILTER 9
FIGURE 2.1: IMPACT PATHWAYS FROM THE SUSTRAIL INNOVATIONS TO SUSTAINABILITY GOALS 12
FIGURE 2.2: LCC COST TREE AND BREAKDOWN STRUCTURE FOR THE SUSTRAIL WAGON 17
FIGURE 2.3: CASE STUDY LOCATIONS 19
FIGURE 3.1: TRACK MAINTENANCE AND RENEWAL COST SAVINGS (CASH FLOW), SUSTRAIL0, UK ROUTE, £ (2015 PRICES) 24
FIGURE 3.2: COST SAVINGS TO INTERMODAL FREIGHT OPERATORS, SUSTRAIL0, UK ROUTE, £ PER ANNUM (2015 PRICES) 26
FIGURE 3.3: TRACK MAINTENANCE AND RENEWAL COST SAVINGS (CASH FLOW), SUSTRAIL1, UK ROUTE, £ (2015 PRICES) 28
FIGURE 3.4: COST SAVINGS TO INTERMODAL FREIGHT OPERATORS, SUSTRAIL1, UK ROUTE, £ PER ANNUM (2015 PRICES) 29
FIGURE 3.5: TRACK MAINTENANCE AND RENEWAL COST SAVINGS (CASH FLOW), SUSTRAIL2, UK ROUTE, £ (2015 PRICES) 30
FIGURE 3.6: COST SAVINGS TO INTERMODAL FREIGHT OPERATORS, SUSTRAIL2, UK ROUTE, £ PER ANNUM (2015 PRICES) 31

List of Tables

TABLE ES.1: RESULTS OF THE SOCIO-ECONOMIC COST-BENEFIT ANALYSIS, SUSTRAIL0,1&2, UK ROUTE 7
TABLE 2.1: BUSINESS CASE FRAMEWORK – IMPACT TABLE (TOP LEVEL) 11
TABLE 2.2: BUSINESS CASE OUTPUTS 13
TABLE 2.3: DUTY REQUIREMENTS FOR IMPROVEMENT, BY PRIORITY LEVEL 14
TABLE 2.4: INNOVATIONS FOR INCLUSION IN THE SUSTRAIL VEHICLES: (I) CONVENTIONAL; & (II) FUTURISTIC 15
TABLE 2.5: BUSINESS CASE SCENARIOS 18
TABLE 2.6: IMPACTS OF SUSTRAIL0,1&2 ON TRACK COSTS 18
TABLE 2.7: IMPACTS OF SUSTRAIL0,1&2 ON FREIGHT OPERATORS' COSTS AND REVENUES 19
TABLE 2.8: ACCESS CHARGE REDUCTION FROM BASE IN EACH OF THE SCENARIOS 22
TABLE 3.1: PAYBACK PERIOD FOR THE SUSTRAIL VEHICLE UNDER VARIOUS SCENARIOS 25
TABLE 3.2: END USERS' FINANCIAL BENEFIT FROM THE SUSTRAIL VEHICLE UNDER DIFFERENT ASSUMPTIONS, UK ROUTE 27
TABLE 3.3: END USERS' FINANCIAL BENEFIT FROM THE SUSTRAIL VEHICLE+TRACK UNDER DIFFERENT ASSUMPTIONS, UK ROUTE 29
TABLE 3.4: END USERS' FINANCIAL BENEFIT FROM THE SUSTRAIL VEHICLE+TRACK WITH INCREASED FREIGHT SPEED, UNDER DIFFERENT ASSUMPTIONS, UK ROUTE 31
TABLE 4.1: SUMMARY RESULTS OF THE SOCIO-ECONOMIC COST-BENEFIT ANALYSIS, SUSTRAIL0,1&2, BG ROUTE 32
TABLE 4.2: RESULTS OF THE SOCIO-ECONOMIC COST-BENEFIT ANALYSIS, SUSTRAIL0,1&2, UK ROUTE 33
TABLE 5.1: VEHICLE INNOVATIONS 36
TABLE 5.2: INFRASTRUCTURE INNOVATIONS 37
TABLE 5.3: PREMIUM RAIL STEEL -INTENSITY OF THE RESULTS 39
TABLE 5.4: PREMIUM RAIL STEEL-MAIN RESULTS 39

EXECUTIVE SUMMARY

The SUSTRAIL research has investigated a wide set of vehicle and track technologies (WP3&4), in search of a package of innovations which together meet the goals of the project: to attract freight towards rail from less sustainable modes (road in particular) by designing a freight vehicle-track system offering higher speed and improved availability at reduced cost; and increasing the sustainability of rail freight, both in environmental and economic terms – for example by reducing noise per tonne-km and improving cost-competitiveness with road freight. The process of narrowing-down a long list of innovations and ultimately demonstrating the value of the chosen package of innovations has been the task of the Business Case. This deliverable summarises the final Business Case. It concludes a series of deliverables that examined the Life Cycle Cost (LCC) and Reliability, Availability, Maintainability and Safety (RAMS) performance of the innovations (D5.1); the end user and environmental benefits (D5.2); the track access charging aspects (D5.3); technical implementation (D5.4) and human factors (D5.7).

The Duty Requirements for the SUSTRAIL innovations were agreed early on (§2.2). Highest priority was given to:

- a modest increase in freight speed (120 to 140kph UK; 100 to 120kph elsewhere) – in order to open up potentially-valuable additional paths on more congested networks;
- optimisation of axle loads – trading-off payload against speed and track damage;
- targeting a reduction in vehicle mass and energy required (20%) – in practice this was traded against an increase in the mass of the disc braking system, which enabled other duty requirements to be met; and
- reduction in track forces (lateral and vertical) through improved bogie design.

Other medium and lower priority duty requirements were listed in §2.2.

A further selection process was undertaken for vehicle innovations (WP3) and separately for track innovations (WP4) taking into account the Business Case framework (§2.3). .

The emerging package of innovations was subjected to LCC and RAMS analysis, whose principal findings were that both the wagon and the track innovations produce savings in life-cycle cost and improvements in availability and mission success measures for rail freight (§2.4).

The LCC and RAMS models were focused on a relatively small part of the rail freight cost base, so work was required in Task 5.2 to aggregate up to track maintenance costs and freight operators' costs, in order to estimate the demand impacts and user benefits. Aggregation was undertaken to provide results at the Case Study route level (§2.5).

Further essential enabling work was carried out to:

- model freight demand in the three Case Studies (mixed-use corridors in the UK, Bulgaria and Spain), estimate the user benefits and the environmental impacts and benefits (§2.6);
- analyse track access charging regimes in place in the EU with a view to making recommendations on how to distribute the whole-system savings achieved by the SUSTRAIL innovations, to the benefit of all parties (§2.7);
- examine implementation issues and opportunities, including timescales to deployment of the technologies chosen for the SUSTRAIL vehicle and track (§2.8).

All of the above was reported in detail in deliverables D5.1-5 and 5.7.

The main findings of the Final Business Case, which are the main subject of this deliverable, are as follows.

The vehicle and track innovations selected are as set out in §2.3. Their purpose, taken together as a package, is:

- to reduce track damage at a given speed and axle-load for intermodal and similar trains;
- to allow a modest increase in maximum freight train running speeds, in order to mix better with other traffic improving reliability, and opening up additional paths on more congested lines;
- to extend the interval for track renewal and maintenance activities through both improved track and track-friendly vehicles;
- to use technology to cut down vehicle and track maintenance activities – for example by using condition monitoring to reduce failures and corrective maintenance costs, and by optimising the design of system components, thereby reducing the life-cycle costs of wagons and track, helping to make rail freight more cost-competitive;
- to improve availability and so help to reduce fleet costs for freight wagons;
- to reduce noise through the use of disc brakes instead of conventional tread brakes;
- by competing more strongly with road freight, to achieve reductions in CO_2 and local air pollutant emissions at the level of the European freight system.

The final outcomes of these various – mostly complementary – effects are best summarised in the socio-economic cost-benefit analysis of the SUSTRAIL innovations (Table ES.1). This shows that: (i) SUSTRAIL can be seen as a win-win intervention – for each impact group (the IM, the freight operator, the end users and 3rd parties) the net impact is positive for the SUSTRAIL package as a whole; (ii) the SUSTRAIL innovations are beneficial in terms of their overall social Net Present Value (NPV), whichever package is chosen (vehicles only/vehicles+track/vehicles+track+enhanced speed); (iii) the package of vehicles+track appears to have the strongest case, across more than one Case Study; except that (iv) when Path Capacity Benefits are introduced, on a route that is already quite congested, such as the UK Felixstowe-Peterborough-Ipswich route, the net benefit of the enhanced speed package appears to overtake the standard SUSTRAIL vehicle+track package.

Alongside this, the Financial Business Case is the other key set of outcomes, and we found positive Net Present values for all industry parties for each of the packages. Further details are given in Chapter 3. The financial analysis demonstrates the inter-relatedness of the Track Access Charge assumptions and the financial outcomes by group, and shows that a reduction in Track Access Charges and a reduction in the capital cost of the SUSTRAIL vehicle are required in order to achieve a viable payback period (5-7 years) for the SUSTRAIL vehicle. The recommendations for adjustment of Track Access Charges to facilitate the deployment of more sustainable vehicles and track are set out in §2.7.1.

			Net Present Value (NPV) @4% for each scenario, €		
			SUSTRAIL0	SUSTRAIL1	SUSTRAIL2
Impact Groups		***Impacts***	(vehicle only)		(140kph)
Infrastructure Manager (IM)	ΔCosts	Track investment	0	-260,777	-260,777
		Track renewals	4,586,538	45,007,611	32,798,176
		Track maintenance - preventive	805,699	6,159,712	5,011,935
		Track maintenance - corrective	1,893,713	1,893,713	1,183,570
		SubTOTAL	7,285,950	52,800,260	38,732,906
	ΔRevenues	Track access charges - intermodal	-7,285,950	-13,394,433	-11,491,462
		Track access charges - other	0	-1,808,674	-1,244,443
		SubTOTAL	-7,285,950	-15,203,107	-12,735,905
	Net Benefit	**SubTOTAL**	**0**	**37,597,153**	**25,997,000**
Freight Operators (FOCs) - intermodal	ΔCosts	Vehicle maintenance costs	27,127,156	27,127,156	25,427,062
		Vehicle ownership costs	-17,471,655	-17,471,655	-17,471,655
		Freight operators' fuel costs	0	0	-18,896,672
		Other operating costs	0	0	0
		Track Access Charges (variable)	7,285,950	13,394,433	11,491,462
		SubTOTAL	16,941,451	23,049,934	550,197
	ΔRevenues	Freight service charges (money)	-13,370,069	-18,045,948	34,195
	Net Benefit	**SubTOTAL**	**3,571,382**	**5,003,986**	**584,392**
Freight Operators (FOCs) - other	ΔCosts	Track Access Charges (variable)	0	1,808,674	1,244,443
		SubTOTAL	0	1,808,674	1,244,443
	ΔRevenues	Freight service charges (money)	0	-1,515,444	-952,588
	Net Benefit	**SubTOTAL**	**0**	**293,230**	**291,855**
End Users - intermodal	ΔUser Benefits	- reduced freight cost	13,370,069	18,045,948	-34,195
		- reliability	4,050,831	6,652,993	4,284,235
		- time savings	0	0	17,924,567
	Net Benefit	**SubTOTAL**	**17,420,901**	**24,698,941**	**22,174,606**
End Users - other	ΔUser Benefits	- reduced freight cost	0	1,515,444	952,587
		- reliability	0	563,946	377,920
		- time savings	0	0	0
	Net Benefit	**SubTOTAL**	**0**	**2,079,390**	**1,330,507**
3rd Parties	ΔBenefits	CO_2 reduction	703,079	4,278,505	4,721,968
		Air pollution reduction	-9,197	2,145,416	1,688,424
		Noise reduction	1,277,439	1,647,927	1,473,094
	Net Benefit	**SubTOTAL**	**693,882**	**6,423,921**	**6,410,392**
Social Net Present Value (NPV)		**TOTAL**	**21,686,165**	**76,096,621**	**56,788,754**

Table ES.1: Results of the socio-economic cost-benefit analysis, SUSTRAIL0,1&2, UK route

1. INTRODUCTION

1.1 The SUSTRAIL Innovations

The SUSTRAIL project aims to contribute to the development of the rail freight system, and to support rail in regaining market share from road transport, by focusing on a combined improvement in both freight vehicles and track:

- The **SUSTRAIL vehicle**, described in deliverable D3.7 (Iwnicki et al, 2015) is designed to provide sustainable, low-impact operation at high speed. The design includes:
  - **bogie and running gear innovations**: primary suspension with double Lenoir links to allow reduced longitudinal stiffness and therefore better steering; inter-wheelset linkages for stability; friction control methods informed by the results of tests carried out during the project; suspension components optimised using computer simulation;
  - **an advanced electronic braking system** – this system is capable of braking the fully laden vehicle and providing wheel slide protection;
  - **innovations in the structural design of the bogie and wagon body** including innovative materials and structural arrangements, optimised using finite element methods to optimise the structural design and achieve significant reductions in weight;
  - **efficient traction systems and condition monitoring systems** were studied and have been taken into account in the design.

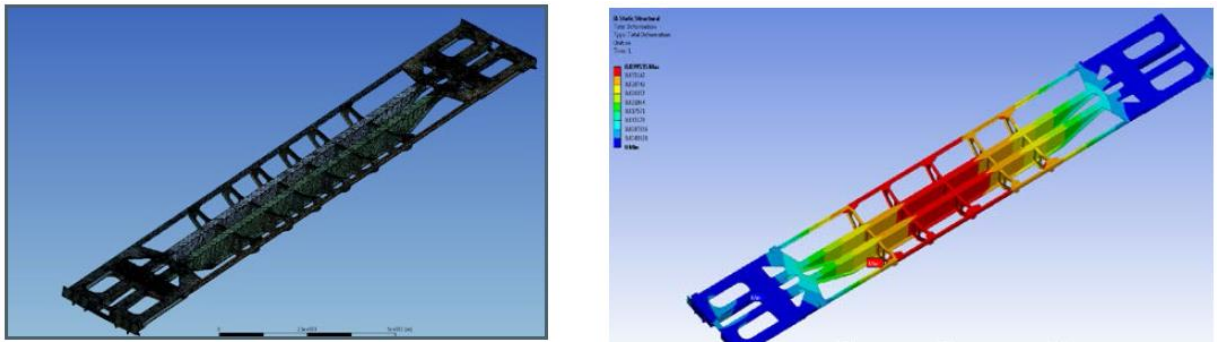


Figure 1.1: Finite element analysis of the lightweight SUSTRAIL vehicle body structure

- The **SUSTRAIL track**, described in deliverables D4.1-5 and summarised in D5.4 (Blacktop et al, 2015) includes one specific improvement and a number of other potential improvements which could be introduced. The specific improvement is the use of Premium Rail Steel on curves of radius 0-1200m, which extends the intervals for maintenance actions and for replacement, so reducing track maintenance and renewal costs.

These innovations are designed not only to reduce costs directly, but to generate cost savings for other rail industry participants, in particular through improved track-train interaction and through savings to the infrastructure manager (IM) that might be passed on through track access charges to freight operating companies (FOCs), and ultimately to the end users – European rail freight customers.

The outcomes of the SUSTRAIL innovations are expected to include:

- higher running speeds – at up to 140kph instead of 120kph on mixed-use passenger and freight lines;
- reduced track damage;
- higher reliability and increased performance of the rail freight system as a whole;
- reduced costs and enhanced profitability for its stakeholders.

1.2 The role of the Business Case in SUSTRAIL

Within SUSTRAIL, the purpose of this work package (WP5) has been:

1. *to make the **Business Case*** for the proposed vehicle and track innovations;
2. *to make recommendations for whole-system implementation*, including phasing-in of novel technologies and strategies for the equitable redistribution of whole-system savings.

During the project, WP5 served as an *iterative filter*, providing feedback to the engineering development work from an economic perspective (Figure 1.2).

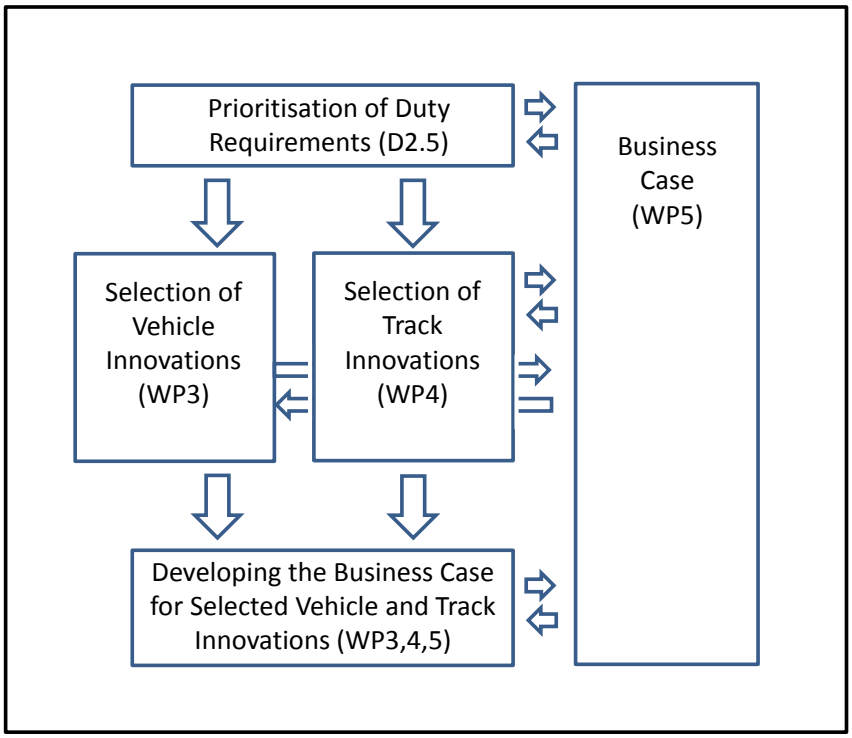


Figure 1.2: Role of WP5 as an iterative filter

The first step was to set out the Business Case framework and to use this early on to help prioritise the Duty Requirements for the SUSTRAIL vehicle and track (see Chapter 2 below). In other words, the project sought to identify which performance parameters were most important for the innovations to address, and what change in those parameters was targeted.

The Business Case framework was then used to support the selection of a final set of vehicle innovations (by WP3) and track innovations (by WP4) to take forward in the SUSTRAIL vehicle and track.

Finally, a Business Case for the chosen SUSTRAIL innovations was prepared in two stages: an Interim Business Case which reported in May 2013 (D5.5, Nellthorp et al, 2013); and the complete Business Case, incorporating a wider range of analysis, which is reported here in this deliverable.

1.3 Scope of this Deliverable

The chapters of this deliverable therefore cover the following aspects of the research:

- the research leading up to the Business Case (Chapter 2);
- the financial Business Case, for industry participants and others (Chapter 3);
- the Socio-Economic Business Case (Chapter 4);
- the implementation of the SUSTRAIL innovations (Chapter 5); and
- key conclusions from the research (Chapter 6).

2. RESEARCH LEADING TO THE BUSINESS CASE

2.1 Business Case framework and method

Central to the SUSTRAIL Business Case is the *impact on stakeholders in the industry*, including the infrastructure managers (IMs), freight and passenger operators, and the end users whose freight is being moved (Table 2.1). It needs to be demonstrated that for these stakeholders the benefits of the SUSTRAIL innovations outweigh the costs.

	Groups			
	IMs	**Train Operators**	**End Users**	**3rd Parties**
Impacts	- changes in costs and revenues	Freight Operators - changes in costs and revenues Passenger Operators - changes in costs and revenues	- changes in costs and benefits	Environmental Externalities - CO_2 & noise Government - grant or subsidy requirements

Table 2.1: Business Case framework – impact table (top level)

The Business Case therefore includes a cost-benefit analysis comprising:

- financial analysis of the impact on IMSs, train operators, end users and government, in terms of net present value (NPV) and payback period – further details follow in Chapter 3; and
- a socio-economic cost-benefit analysis covering all parties (Chapter 4).

More widely, the SUSTRAIL research is expected to contribute to a *more sustainable European freight sector*. This increase in sustainability is to be achieved through both:

(i) attracting freight market share towards rail from less sustainable modes (road in particular) by designing a freight vehicle-track system offering higher speed and improved availability at reduced cost; and

(ii) increasing the sustainability of rail freight itself, both in economic and environmental terms – for example by reducing noise per tonne-km and improving cost-competitiveness with road freight.

SUSTRAIL has assessed how the proposed changes in the vehicle-track system will impact initially on costs and system performance, and finally on these wider goals of rail market share and sustainability (see Figure 2.1 below). These wider impacts have been integrated into the cost-benefit analysis, as far as is technically feasible (Chapter 4).

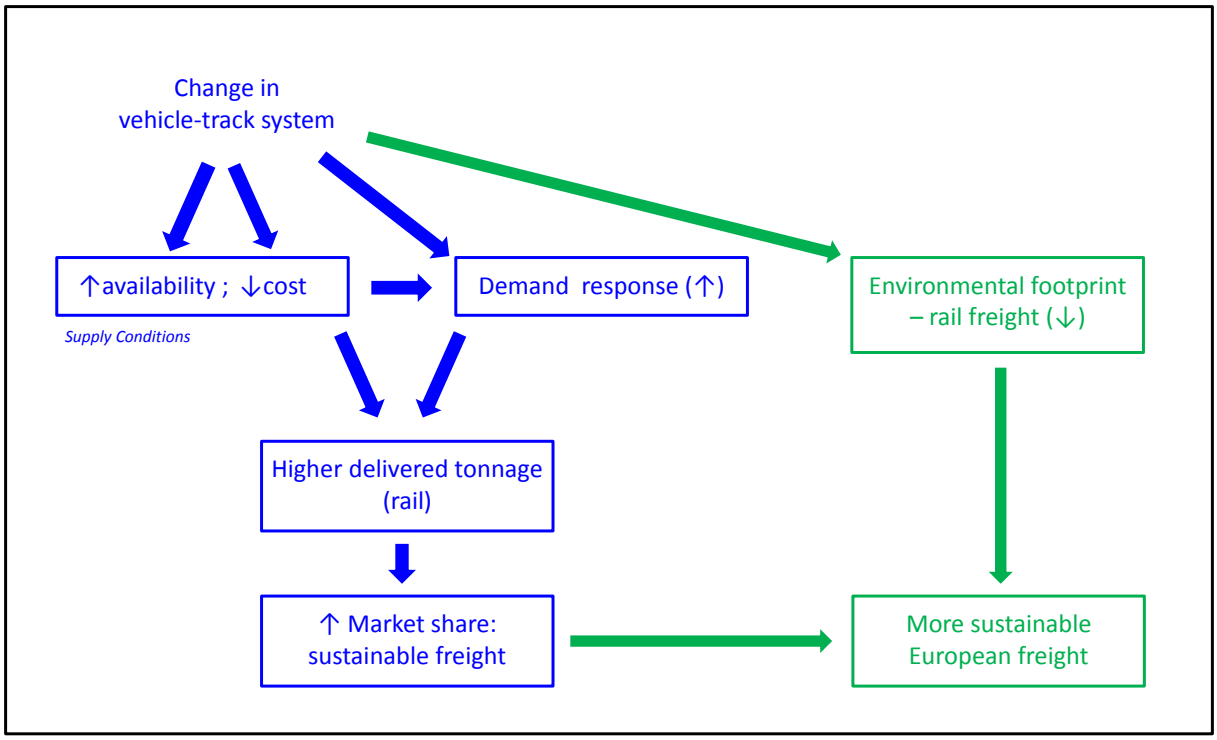


Figure 2.1: Impact pathways from the SUSTRAIL innovations to sustainability goals

The changes in costs were estimated using Life Cycle Costing (LCC) analysis for both the IMs and train operators, and the impacts on freight train performance were measured using a Reliability, Availability, Maintainability and Safety (RAMS) analysis (see section 2.6 below).

Implications for user and environmental benefits were estimated in three case studies, based in the UK, Bulgaria and Spain (see section 2.8). This work includes demand analysis for the purpose of estimating:

- the value of the change in the vehicle-track system to end users;
- their expected demand response to the rail freight system improvement;
- the implications for market shares.

These user and environmental benefits are reliant on the outputs from LCC and RAMS analysis, and also on assumptions about track access charges between the IM and the train operators. There was a distinct task (5.3) dedicated to understanding the potential for differentiated access charges reflecting the relative damage cost of different vehicle-types (see section 2.5). In the Business Case, track access charges will influence the flow of revenue from train operators to the IM, and hence the distribution of whole-system savings.

Moreover, the Business Case is also concerned with *implementation* of the vehicle and track innovations proposed by the project. IMs and train operators have a wide range of technologies in use at any time, and the innovations need to be compatible with these to ensure that the operation of the railway system remains integrated. Therefore there was a research Task (5.4) focusing on: interfacing the innovations with existing track forms and vehicles, human factors and operational aspects.

In summary, therefore, the outputs of the Business Case for the selected SUSTRAIL innovations comprise the following items (Table 2.2).

Item	Analysis outputs
1.	Description of the innovation
2.	Rationale for the innovation
3.	LCC and RAMS analysis – main findings
4.	Cost-benefit analysis: • financial case for industry stakeholders • socio-economic case
5.	Impact on rail market share, CO_2 and other emissions
6.	Technical implementation and phasing – recommendations

Table 2.2: Business Case outputs

2.2 The prioritisation of Duty Requirements

An important step in the first year of SUSTRAIL was the definition of duty requirements. These include: essential duty requirements which must be met by the innovative freight wagon and track – for example, a large number of TSIs and standards applicable to railways which are expected to remain fixed; and also duty requirements for improvement, which specify changes above and beyond the essential duty requirements which will allow rail freight to become more sustainable and gain market share (D2.5, Beagles et al, 2012).

A large number of ideas for new duty requirements were considered. In order to prioritise among the suggested new duty requirements, they were assessed against a set of criteria derived from the Business Case framework[1]. The prioritisation exercise made use of the available information at this stage of the project, including operators' and IMs' inputs, as well as the evidence from the SUSTRAIL research (Tasks 2.1 to 2.5.3), and the findings of a workshop focusing on this topic, held on 12 July 2012 in Sofia, Bulgaria.

Emerging from the prioritisation was the set of new duty requirements shown in Table 2.3. These were rated High/Medium/Low priority, with the implication that: High priority items would be pursued most urgently, using the majority of the resources; Medium and Low items would be given less priority, however even the Low items have potential – their Low priority reflects greater risks (in terms of technical viability) and/or smaller apparent rewards.

These duty requirements are about determining what the SUSTRAIL improvements should be, in terms of the parameters targeted, the direction of change, and – particularly where research evidence exists – the magnitude of the target.

[1] The criteria were: availability; cost; service quality; and environmental footprint; plus technical viability. Technical viability referred to the operators', IM's and research team's judgement about whether the duty requirements are: (i) capable of being addressed by the project with 3 years' intensive research; and (ii) implementable by the industry.

Priority Level	Duty Requirements for Improvement	System
High	1. Modest increase in freight speed (e.g. 120-140kph UK; 100-120kph ES,BG)	whole
	3. Optimise axle load limits (22.5t / 25t / 17-20t)	whole
	7. (20%) reduction in energy used by rail vehicles + Vehicle Green Label	vehicle
	12. Improve bogie design to reduce lateral forces (by 50%)	vehicle
Medium	5. Reduce vertical ride force to match passenger vehicle at equivalent axle load (by suspension improvements)	vehicle
	8. (20%) reduction in unsprung mass of freight vehicle	vehicle
	2. Uniform vertical stiffness (track) - optimise between 50-100 kN/mm	track
	9. Optimise (potentially double) service life of track components	track
	10. Combine components that have a similar service life (harmonise MTBF)	track
	6. Reduced rate of tolerable defects	track
	4. More reliable insulated rail joints (life*5)	track
Low	11. Independent power supply (wagon or train based) - for braking & refrigeration	vehicle
	13. Increased loading space	vehicle

Table 2.3: Duty requirements for improvement, by priority level

2.3 The selection of vehicle and track innovations

2.3.1 Selection of vehicle innovations

At the next stage of SUSTRAIL, the research team began to translate these requirements for improvement into a set of proposed technologies and engineering solutions to incorporate in the SUSTRAIL vehicle.

Again, the options were assessed using a set of criteria derived from the Business Case framework, this time augmented with greater detail where the engineering research team felt able to give it: for example, specific attention was given to production costs and availability for mass production, and the criteria were given numerical weights based on the research team's judgement about the importance of each item in the overall case. Decisions were reached about the inclusion/exclusion of each innovation, taking into account this assessment, at the WP3 workshop on 6 December 2012 in Genova, Italy.

Note that these innovations are packaged into two improved vehicles: (i) labelled the Conventional vehicle, or 'Demonstrator 1', including 17 of the 39 technical innovations considered; (ii) labelled the Futuristic vehicle, or 'Demonstrator 2' including 30 of the 39 technical innovations considered. These vehicles would be compared with a typical current UIC Class R/S flat container wagon with Y25 bogies, for Business Case purposes. In practice, the majority of the research effort in WP3 has focused on the improved Conventional vehicle, or 'Demonstrator 1', therefore we deal with the Futuristic vehicle using sensitivity testing in the Business Case. 'Demonstrator 1' is currently being built as a real vehicle by REMARUL Engineering for testing during 2015.

WP3 "THE FREIGHT TRAIN OF THE FUTURE" - Assessment of Potential Technology Innovations												
FOCUS AREA	INNOVATION	Compliance with Duty Requirements (as set out in D2.5)	Technological Benefit	Production Costs	Availability for Mass Production	Reliability	Maintainability	Sustainability (Energy consumption, damage)	Weighted Priority Index	INCLUSION IN SUSTRAIL VEHICLE?		Notes
										Conventional	Futuristic	
Weight		0.05	0.1	0.1	0.15	0.25	0.175	0.175	1			
RUNNING GEAR (3.1)	Modified Y25 primary springs	7.9	6.3	6.3	9.0	7.4	7.1	7.3	7.40	Yes	Yes	
	Rubber springs	7.1	5.9	4.6	7.3	6.3	4.9	6.9	6.14	No	No	
	Double lenoir dampers	7.4	5.7	5.0	8.8	6.7	6.7	6.8	6.78	Yes	Yes	
	Wedge dampers	5.3	4.2	6.1	8.2	6.0	5.8	5.8	6.06	No	Yes	
	Hydraulic dampers	7.2	7.7	3.9	8.0	5.3	5.0	6.6	6.07	No	Yes	
	High resistance damping material	5.9	5.0	5.3	6.5	6.3	6.5	6.8	6.18	Yes	Yes	STP
	HALL bushes	7.6	7.3	4.0	6.9	5.5	5.5	7.1	6.12	No	No	
	Pusher springs	6.8	4.8	5.6	7.3	5.8	5.9	6.0	6.00	No	No	
	Steering linkages	8.1	8.1	3.6	6.8	6.0	5.0	8.3	6.42	No	Yes	
	Centre pivot stiffness	6.1	4.9	4.8	6.6	6.5	5.8	6.5	6.03	No	Yes	
	Axle casting	7.6	7.2	5.8	7.1	7.9	6.7	7.4	7.19	Yes	Yes	
	Novel wheel steel	7.0	6.5	5.5	7.3	7.6	7.5	7.4	7.14	Yes	Yes	
	Novel wheel shape	6.6	5.5	5.7	7.0	7.5	7.5	7.2	6.97	Yes	Yes	
	Resilient wheels	5.5	4.9	3.0	4.6	3.6	4.1	5.2	4.29	No	No	
TRACTION AND BRAKING (3.2)	Disk brakes	7.4	7.4	3.3	7.0	6.6	5.3	6.5	6.21	Yes	Yes	in comparison include
	Electronic distributor	7.0	6.2	3.8	6.3	6.0	4.8	6.7	5.81	Yes	Yes	
	Independently rotating wheels	4.8	4.3	2.4	3.6	3.8	3.2	3.6	3.58	No	Yes	to be considered GTU
	Use of friction modifier at wheel	7.0	6.7	4.4	5.4	5.9	4.7	6.7	5.74	No	Yes	
	Brake pad with friction modifier	7.7	7.1	5.3	5.6	6.4	6.0	7.0	6.35	No	No	
	Traction motor "Induction"	7.5	7.5	4.0	7.5	6.0	6.0	7.5	6.51	Yes	No	
	Traction motor "Permanent Magnet"	8.0	7.7	3.0	7.0	6.7	6.0	8.3	6.69	No	Yes	
	Power electronic drive "Multi level topology M2C"									No	Yes	
	Power electronic drive "Silicon Carbide SiC"									No	Yes	
	Energy storage "Batteries"	5.0	4.0	3.5	7.5	5.0	5.0	5.0	5.13	Yes	Yes	not in demonstrator
	Energy storage "Ultra capacitors"	6.5	4.0	3.0	6.0	5.5	7.0	6.5	5.66	Yes	Yes	not in demonstrator
	Medium frequency transformer for AC-grid									No	Yes	
BODY AND BOGIE STRUCTURES (3.3)	Lightweight bogie based on novel materials	8.3	8.0	3.7	4.8	5.2	5.3	7.1	5.78	No	Yes	
	Lightweight bogie based on hybrid solution	8.2	8.3	4.2	4.9	5.5	5.0	7.7	5.99	No	Yes	
	lightweight bogie based on shape and components	8.3	7.9	5.3	5.9	6.9	7.2	7.3	6.89	Yes	Yes	
	Composite bogies	8.4	7.4	2.7	3.2	4.6	4.2	6.6	4.94	No	No	
	Aerodynamic fairings	7.1	6.3	5.2	6.4	6.6	5.4	6.6	6.22	No	Yes	
	Light weight body based on novel steels	8.9	8.2	5.1	5.7	6.4	6.2	7.4	6.61	Yes	Yes	
	Light weight body based on aluminium alloys	8.6	8.0	4.2	5.5	6.1	6.2	7.1	6.33	No	No	
	Light weight body based on Composite materials	8.6	8.2	3.8	3.8	4.5	4.6	7.0	5.36	Yes	Yes	some components only
CONDITION MONITORING (3.4)	Axle monitoring through acoustic emission	7.9	8.0	4.3	4.6	5.9	6.3	7.6	6.21	No	Yes	
	Axle monitoring through vibration analysis	8.3	8.1	5.8	6.3	6.7	6.9	8.2	7.07	Yes	Yes	demonstration through external
	Energy harvesting	8.1	8.1	5.0	6.0	6.1	6.3	7.8	6.61	Yes	Yes	
	Machine vision technology for monitoring wheels	6.7	6.4	4.3	4.6	5.2	4.8	5.8	5.25	No	No	wayside
	Thermal sensors to monitor axle boxes	7.6	7.2	5.0	5.4	5.9	4.9	6.3	5.85	Yes	Yes	KES

Table 2.4: Innovations for inclusion in the SUSTRAIL vehicles: (i) Conventional; & (ii) Futuristic

2.3.2 Selection of track innovations

WP4 undertook a prioritisation of the track innovations. The method adopted was: to assemble and review existing research, including the INNOTRACK priorities, internal Network Rail prioritisation work, and the SUSTRAIL FMEA Risk Priority Index; the emerging 29 potential track innovations were listed and analysed in D5.5, Chapter 5 (Nellthorp et al, 2013); the innovations in this long-list were then the reduced to a shortlist by the WP4 partners, taking into account the potential impact on the Risk Priority Index and the broad order of cost of the innovation. The shortlisted innovations are described in D5.4, Appendix 1 (Blacktop et al, 2015) and in D5.1 (Rantatalo et al, 2015):

- Premium Rail steel – on plain line track, and at switches and crossings;
- Fatigue life prediction of modern rail steels;
- Rail profile changes to reduce rail wear and deformation;
- Sensor-integrated geogrids for monitoring of the railway substructure;
- Track force measuring systems to pinpoint vehicles that cause abnormal degradation of the track;
- Improved switch lubrication testing;
- Smart washer technology to enable remote monitoring of critical fastenings on the track;
- Novel rail fastening devices to maintain gauge and improve damping properties of the track;
- Transition zones to bridges;
- Under sleeper pads.

During the development of the Life Cycle Costing (LCC) and RAMS modelling, further data was sought in order to simulate the costs and performance impacts of these innovations. In many cases, however, the impacts could not be simulated due a lack of suitable data: for example, a lack of data on the cost implications due to a lack of purchase, implementation, operation, maintenance and disposal cost evidence; and in general a lack of relevant data on performance in real applications.

As a result, it was decided to focus the Business Case analysis on the implementation of Premium Rail steel at plain rail curves of radius <1200m. The primary purpose of this innovation is to reduce rail wear and rolling contact fatigue damage on tighter-radius curves. Premium rail steels such as HP335 and MHH375 offer increased hardness and more beneficial microstructures than conventional plain line rail steels (R260), resulting in reduced rail wear and rolling contact fatigue damage with resulting reduced replacement regimes and lower levels of inspection and grinding. Trial sites on the UK network have confirmed the performance predictions. UK approval of HP335 for general use has been obtained. EN approval/certification of HP335 would be required for use European-wide, while MHH375 is already covered within the EN specification.

2.4 LCC and RAMS modelling

The LCC and RAMS models were developed to assess the innovations from a holistic approach (D5.1, Rantatalo et al, 2015). This holistic approach aims to reflect how the track and the wagons interact from a cost and performance perspective. In particular, the track maintenance actions are affected by a track-friendlier SUSTRAIL wagon and the economic benefits for the IM can be quantified. Effects in the opposite direction, how the track will affect the wagon, have not been implemented in the model due to lack of data.

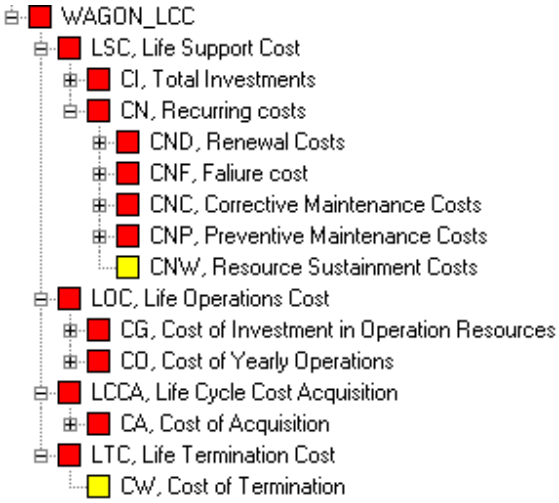


Figure 2.2: LCC cost tree and breakdown structure for the SUSTRAIL wagon

The LCC model predicts the cost profile for the wagon and for the track over a 30 year period. The results of the simulation show that the technical performance of the SUSTRAIL wagon is better than the benchmark wagon. The estimated availability of the benchmark wagon is about 95% while that of the SUSTRAIL wagon is estimated to be 99%. The main factor responsible for the lower availability of the benchmark wagon is the increased total amount of logistics and waiting time at the workshop due to a higher failure rate. In addition, the mission success rate of the SUSTRAIL and benchmark wagons is similar to the availability of their respective availability measures. From a cost perspective, the cost of acquisition of the improved wagon was initially estimated to be approximately 70% higher than the benchmark wagon: at this level of cost, the reduced cost of maintenance and failure does eventually pay off, but only in the long run. It was therefore judged important to focus effort on bringing down the acquisition cost of the SUSTRAIL vehicle, for example taking advantages of economies of scale in mass production.

The break-even point for the SUSTRAIL wagon excluding any benefit from track access charge reductions is quite late, at 23 years (see Chapter 3 for a full discussion), however there are promising benefits from operation and track performance viewpoints. Furthermore, the availability performances of the benchmark track and wagon, benchmark track and improved wagon, improved track and wagon and improved track and wagon with speed increase are estimated to be 95%, 97%, 99% and 97% respectively, (as previously mentioned, how the track innovation will affect the wagon is not included). Even though the differences in the technical performance of the four cases are not pronounced, the cost implication justifies the implementation of the SUSTRAIL scenario (improved wagon and track) without speed change. More dynamic simulation is needed to validate the opined performance of the proposed improvement with speed change. It is estimated that wagon improvement with benchmark track will give at least 5% reduction in the life cycle cost over 30 years with focus on curves in the simulated route (UK1). Further improvement of the track with premium rail together with improved wagons presents about 61% reduction in the LCC. In the case of the track improvement with speed change, the estimated reduction in the LCC by 43% is based on expert assessment. It is suggested that additional dynamic simulation is required to further establish the expert judgement and these conclusions.

It is important to note that this LCC analysis has been "partial" in nature. That is, only the cost elements where significant cost changes between the base scenario and the modelled

scenarios have been modelled. The % reductions in cost quoted above need to be interpreted in this context.

2.5 Aggregation and the Impacts of SUSTRAIL Innovations

A substantial task was to scale-up the LCC and RAMS results to the Case Study corridor level. In the LCC analysis (D5.1), most of the track cost items are based on the curves of radius 0-1200m, which make up only a proportion of the total track length (e.g. 7.1% of the UK case study route). Using data on track maintenance and renewal costs for whole network and for the Case Study routes, the LCC and RAMS results were scaled-up. In parallel with this, since wagon LCC costs represent less than 10% of the freight operating companies' cost base, overall estimates of freight operators' costs were obtained, for use in the freight demand modelling and cost-benefit analysis in D5.2.

Bringing these elements together, the impacts of the SUSTRAIL vehicle and track on the Infrastructure Manager (IM) and the Freight Operators were estimated. Tables 2.6 and 2.7 give the results for the UK Case Study. The SUSTRAIL vehicle and track together were found to have the greatest overall impact on costs: overall a 10% saving to the IM and 2.4% saving to the freight operators. These results correspond to the three SUSTRAIL scenarios set out in Table 2.5

	Scenario			
	BASELINE	**SUSTRAIL0**	**SUSTRAIL1**	**SUSTRAIL2**
Vehicles	Benchmark	SUSTRAIL vehicles	SUSTRAIL vehicles	SUSTRAIL vehicles
Track	Benchmark	Benchmark	SUSTRAIL track (on curves radius 0-1200m)	SUSTRAIL track (on curves radius 0-1200m)
Max Speed (freight)	Benchmark (120kph)	Benchmark (120kph)	Benchmark (120kph)	140kph

Table 2.5: Business Case scenarios

	Track LCC data % changes:			Track cost % changes at route level:		
	SUSTRAIL0 (vehicle only)	SUSTRAIL1	SUSTRAIL2 (140kph)	SUSTRAIL0 (vehicle only)	SUSTRAIL1	SUSTRAIL2 (140kph)
Track Maintenance and Renewal Costs				-1.6%	-10.1%	-7.5%
Maintenance				-0.8%	-2.4%	-1.8%
Corrective maintenance	-80%	-80%	-50%	-0.6%	-0.6%	-0.3%
Preventive maintenance	-6%	-45%	-37%	-0.2%	-1.8%	-1.5%
Renewals				-0.8%	-7.7%	-5.6%
General renewals	-10%	-86%	-60%	-0.8%	-7.8%	-5.7%
Investments/innovations	0%	2%	2%	0.0%	0.05%	0.05%

Table 2.6: Impacts of SUSTRAIL0,1&2 on track costs

Impacts on Freight Operators	%change	Baseline	SUSTRAIL0 (vehicle only)	SUSTRAIL1	SUSTRAIL2 (140kph)
Freight Operators' costs		Base	-1.8%	-2.4%	-0.5%
Vehicle maintenance costs		Base	-61%	-61%	-58%
Vehicle ownership costs		Base	46%	46%	46%
Freight operators' fuel costs		Base	No change	No change	3.7%
Other operating costs		Base	No change	No change	No change
Track Access Charges (variable) - SUSTRAIL vehicles		Base	-10.4%	-17.4%	-15.2%
Track Access Charges (variable) - other vehicles			0.0%	-6.9%	-4.8%
Freight service charges (money)		Base	-1.8%	-2.4%	-0.5%

Table 2.7: Impacts of SUSTRAIL0,1&2 on freight operators' costs and revenues

2.6 User and environmental benefits

Deliverable D5.2 (Nellthorp et al, 2015) reports the assessment of the impacts of the SUSTRAIL improvements under the following of headings, which form part of the Business Case:

- **freight user benefits** – from the freight customer's perspective, the SUSTRAIL improvements should improve the competitive position of rail freight versus other modes – we use aggregate models of freight demand to estimate the potential impact of the SUSTRAIL improvements on mode share, and provide insights into the benefits to those end users;
- **environmental benefits** – focusing on CO_2, air pollution and noise impacts;
- **potential passenger benefits** – since running freight trains at higher speed should free some paths for additional passenger services, on busy mixed-use lines.

User benefits were measured using a set of three Case Studies, each of which included its own analysis of the freight market. The locations of the three Case Studies are shown in Figure 2.3:

1. in the UK – the Felixstowe-Peterborough-Nuneaton corridor;
2. in Bulgaria – from the Greek and Turkish borders in the east to the Serbian border in the west; and
3. in Spain – the Mediterranean corridor from Valencia to Tarragona.



Figure 2.3: Case Study locations

The UK Case Study used the 'LEFT' freight model to model the impact of the SUSTRAIL innovations on the cost and performance of rail freight in the Case Study corridor, and to predict the increase in rail's mode share on intermodal traffic: a 7.5% increase was predicted as a result of the SUSTRAIL improvements.

The Bulgarian Case Study used a set of customised models for the SUSTRAIL project, building on previous forecasts of population and freight demand growth in the country. The Bulgarian case includes very large untapped markets for intermodal rail freight from/to the ports of Varna and Burgas, as well as international transit traffic between the 'core markets' of the EU in Germany, France, etc and countries to the east and south both inside and outside the EU. As in the UK Case Study, a logit model was used to forecast the rail-road mode split. The model predicted a transformational increase of up to 83% in the market served by rail.

The Spanish Case Study made use of data from the ADIF Network Statement and the Spanish Railway Observatory (OFE) to develop an analysis of the SUSTRAIL improvements in the context of the Mediterranean corridor between Valencia and Tarragona. This case study also benefitted from collaboration with the infrastructure managers and the operators involved in the rail industry in Spain. Confidentiality of freight contracts, however, put some limits on data availability. Based on the analysis undertaken, a 13% increase in intermodal rail demand was predicted.

The corresponding user benefits and environmental impacts are presented as part of the socio-economic Business Case findings in Chapter 4 below.

2.7 Track Access Charges research

A key economic interface between infrastructure managers and freight operators is the track access charge regime: payments by train operators to infrastructure managers for the incremental costs associated with running the train service. Access charges are the key mechanism by which infrastructure cost improvements are passed through to freight operators and, in turn, to freight users. Similarly, suitable discounts in track access charges for different vehicle types can incentivise the adoption of track friendly vehicles. This is an important incentive given that track friendly vehicles may imply higher capital costs for operators. To build a financial case for operators to adopt these vehicles, reductions in on-going costs need to be present and access charges are such a cost (they are incurred whenever the vehicle is used).

In SUSTRAIL new empirical research has been undertaken to understand how costs (and not just damage) vary with traffic of different types. The research within SUSTRAIL on access charges has advanced the understanding of railway infrastructure marginal costs associated with railway traffic and also researched how implementing price incentives (via differentiated access charges) has influenced operator behaviour. New work has been undertaken in integrating the two main approaches (engineering and econometric) to analysing the direct cost to the infrastructure manager associated with running additional traffic. Further new work has been undertaken to understand renewals costs and traffic disaggregation in the econometric approach.

Work has also been undertaken to assess the effectiveness of existing access charge differentiation e.g. by vehicle characteristics. The country with the most highly differentiated track access charges by type of vehicle is Britain, and it appears that even the relatively modest differentiation now in place is sufficient to influence purchasers of new vehicles to fit track-friendly bogies. The current charge differentials are not in general high enough to lead to premature retirement of existing vehicles. However, were the 'central' charge to be raised (as was discussed during the most recent review of track access charges during 2013) then the

differential either side of the central charge would be greater, probably providing a greater incentive to retire the least track-friendly wagons early and/or to invest in the 'most' track-friendly bogies. Of course, this would be likely to have knock-on consequences for operator costs and the overall competitive position between rail and road freight.

Differentiated access charges may be ineffective due to:

- the long lives of wagons; this has led to the current low level of replacement investment
- the relatively small size of discounts for track-friendly bogies
- vehicles running in a variety of countries (common in continental Europe), either on international traffic or because they may be moved between countries in the course of their lives; incentives for track-friendly bogies (however small) are not applied in every country
- the risk involved in buying a more expensive wagon that will only recoup its cost if differentiated access charges continue throughout its life

The effect of these factors might be lessened by introducing larger differentials, but a constraint that reduces the ability to set such wide differentials is that access charges cannot be less than the direct cost to the infrastructure manager of running the vehicle, as set out in existing EU legislation (e.g. Directive 2001/14).

The introduction of noise-differentiated charges, in so far as reduced noise emissions may be linked with track-friendly bogies, may serve to increase take-up of track-friendly bogies across mainland Europe. However, the diversity of charging structures and levels found in Europe means that the impact of incentives is limited.

There is less evidence that track access charges could be used to encourage speeding up of freight trains to increase track capacity, particularly since faster vehicles are more damaging. Clearly there are fears that this could lead to complex charges, with different incentives leading in different directions. It appears that the use of charging to encourage the operation of freight trains at higher speeds needs to be simple and its implications need careful thinking through.

2.7.1 Strategy for access charge differentiation in the SUSTRAIL Business Case

To be useful to the wider context of SUSTRAIL, the research contributions have to be interpreted within the EC charging principles such as Directive 2001/14. These EC directives imply that while charges should be based on direct (marginal) cost, mark-ups are allowed provided that they are non-distorting. We proceed with the current access charge systems, both in terms of levels of changes and existing differentiation in each of the three case study countries as the 'base case'.

In terms of enhancing the rail freight offering and incentivising the implementation of the SUSTRAIL innovations, the project requires access charges to:

1) Pass through infrastructure cost savings resulting from technological innovations to the infrastructure (as studied in WP4) to freight and passenger operators via lower track access charges and ultimately to freight and passenger users. Not all infrastructure cost savings are passed through, only the proportion which is variable with traffic as this reflects the change to marginal costs of running traffic.
2) Redistribute infrastructure cost savings to freight operators if freight operators utilise track friendly vehicles. Ultimately we would expect this cost saving to be passed on to freight users given the competitive nature of the industry.

The principle that access charges should reflect the infrastructure damage (and thus cost) incurred from running a train service, implies that the whole cost saving of any infrastructure cost reduction should be fully reflected in changes in access charges. So, if infrastructure

costs decrease 5% across all vehicle types as a result of the SUSTRAIL infrastructure innovations, then access charges should fall 5% for all services. This effectively means that the whole of the saving relating to the proportion of cost variable with traffic is passed through to the operators of train services (both passenger and freight). This reflects the fact that the cost to the infrastructure manager to remedy damage from a train service has fallen. Such a mechanism allows the proportion of infrastructure cost recovered from charges to remain the same before and after the innovations. Importantly, the IM can retain a substantial share of the cost saving from introducing infrastructure improvements because a substantial share of infrastructure costs do not vary with usage.

Implication: With respect to *Infrastructure* innovations, the proportionate change in infrastructure cost will be reflected in the same proportionate change in (variable) access charges relative to the base case.

With respect to infrastructure cost savings arising from innovations to the vehicle, the principle that access charges should reflect the damage (and thus cost) caused to the infrastructure from running the service implies that 100% of the infrastructure cost reduction should be passed through to operators as a reduction in access charges. However, this reduction should be specific to those vehicles that do the lower amount of damage (as opposed to being applied to all vehicles).

Implication: With respect to *Vehicle* innovations the absolute change in infrastructure costs resulting from running the less damaging vehicles should be passed to the operators of those vehicles.

The above two strategies to adjust track access charges ensures that, with respect to infrastructure improvements, the cost recovery rate for the infrastructure manager remains the same and with respect to vehicle improvements, that operators pay to reflect the damage that they cause to the infrastructure.

Following the LCC analysis and bespoke engineering damage simulation of the vehicle on the track undertaken in SUSTRAIL WP3, the access charge reductions (relative to the base vehicle(s)) were those shown in Table 2.8.

	SUSTRAIL 0 – vehicle improvement	**SUSTRAIL 1 – vehicle and track improvement**	**SUSTRAIL 2 – vehicle track and speed improvement**
Vehicles within the SUSTRAIL vehicle class	10.4%	17.4%	15.2%
Other vehicles	0%	6.9%	4.8%

Table 2.8: Access charge reduction from base in each of the scenarios

Note that the SUSTRAIL vehicle requires a discount because it does less damage to the track than the base vehicle.

2.8 Implementation research

Innovations cannot be considered to be useful if they are not implemented. The wide range of innovations considered within the SUSTRAIL project all have potential benefits, but this alone will not necessarily mean they will be taken up by the rail industry. It is important

within the project to consider the barriers to their implementation and demonstrate reasons to adopt them.

There are three key components in assessing implementation:

- Financial case for each industry player, in particular the operator of the SUSTRAIL vehicle and the infrastructure manager. This is set out in section 3.
- Technological implementation issues such as technological readiness and phasing issues. These issues are discussed in section 5.1.
- Human factor issues, as summarised in section 5.2

2.9 The Interim Business Case

An interim Business Case was prepared in 2013, with only illustrative LCC and RAMs outputs at that stage. The main aim was to validate the methodology, to progress the case studies, and to set out the steps to completion, and this was reported in D5.5 (Nellthorp et al, 2013).

Building on the interim Business Case, the Final Business Case now incorporates:

- the final LCC and RAMS research reported in D5.1 (Rantatalo et al, 2015);
- the user and environmental benefits analysis in D5.2 (Nellthorp et al, 2015);
- the Track Access Charges research in D5.3 (Wheat et al, 2014);
- the Implementation research reported in D5.4 (Blacktop et al, 2015) and human factors analysis in D5.7 (Milotti et al, 2015).

The results are presented in the remaining chapters of this deliverable:

Ch 3. The Financial Business Case

Ch 4. The Socio-Economic Business Case

Ch 5. Implementation of the SUSTRAIL innovations.

3. THE FINANCIAL BUSINESS CASE

3.1 Outline of the analysis

The following analysis compares the three SUSTRAIL scenarios (Table 2.5) with the Baseline scenario. The three SUSTRAIL scenarios include:

- SUSTRAIL0 – the SUSTRAIL vehicle only
- SUSTRAIL1 – the SUSTRAIL vehicle and track
- SUSTRAIL2 – the SUSTRAIL vehicle and track, and a higher freight operating speed (140 vs 120kph).

In each SUSTRAIL scenario, we consider the financial impacts on IMs, freight operators and end users, compared with the baseline of no SUSTRAIL improvements.

3.2 Results for SUSTRAIL Vehicle

3.2.1 Impact on the Infrastructure Manager

Introduction of the track-friendly SUSTRAIL vehicle creates a stream of net benefits for the IM, as a result of savings in track maintenance and renewal costs (Figure 3.1). These savings amount to a potential **1.6% reduction overall in track maintenance and renewal costs**, if the intermodal fleet was fully replaced with SUSTRAIL vehicles.

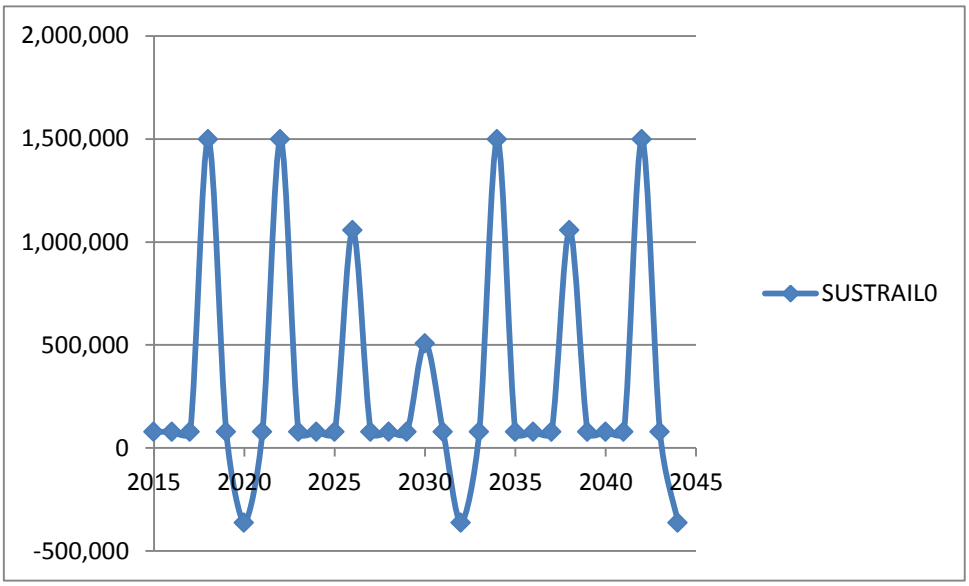


Figure 3.1: Track maintenance and renewal cost savings (cash flow), SUSTRAIL0, UK route, £ (2015 prices)

Assuming a 4% real discount rate for the IM (equivalent to a 6% nominal discount rate on the IM's funding offset by 2% general price inflation), we obtain a positive Present Value of Benefits to the IM of around £5.5million (€7.3million) over 30 years in the UK Case Study.

The savings in the Bulgarian Case Study were much larger (€190million PV@3%) due to the amount of freight being transported by rail (trains amounting to 31million gross tonne km vs 4million gross tonne km) and the distance being larger (368km vs 257km route length).

The savings in the Spanish Case Study were equivalent to €4.8million (@4%), assuming the same treatment of track renewals as in the UK Case Study (i.e. that approximately the same

saving in renewals cost to the IM should be assumed as compared to maintenance cost – and this would supplement the LCC results).

3.2.2 Impact on the Freight Operators

The direct impact is an **11.8% reduction in intermodal wagon ownership and maintenance costs** over the life of the wagon. Initial capital costs increase by 75%, whilst all other costs decrease and the wagon's residual value at the end of 30 years increases.

In addition, if the IM passes on its cost saving to the Freight operators as indicated in §2.7.1, we expect to see a **10.4% reduction in Track Access Charges to intermodal wagons**.

Payback period is a key indicator for the Freight operator. The payback period refers to the number of years after acquisition of the SUSTRAIL vehicle that the operator makes a benefit at present values over the conventional vehicle. It is important because although the LCC analysis indicates a net benefit to the operator from using the SUSTRAIL vehicle, in practice operators will be unwilling to take on the risk in the forecast unless the payback period is sufficiently short.

The LCC analysis reported above considered the majority of factors affecting the operation and acquisition of the SUSTRAIL vehicle. However it did not consider any discount in track access charges associated with this vehicle relative to the base (benchmark) vehicle. Such a reduction can be justified because the use of the SUSTRAIL vehicle results in less damage to the track and less remedial cost to the infrastructure manager. Section 2.7.1 set out the access charge reductions for each scenario.

In addition, the biggest hurdle for achieving a competitive payback period is the cost of acquisition (capital cost). The LCC analysis indicates that the SUSTRAIL vehicle's capital cost is 175% of that of the benchmark vehicle. There is much uncertainty in this figure. In particular it is not unreasonable that under mass production scenarios the capital cost increase could fall to only one half of the current increase over the benchmark vehicle (137.5% of the benchmark vehicle's capital price), i.e. €111,000 instead of €141,000.

Finally, in terms of specifying payback scenarios, it is important to recognise that commercial organisations require a return on capital; analysis indicates that the rail freight market requires 7% real return (9% nominal). We tested this against the 3% assumed in the LCC analysis (3% is close to the social discount rate used in the cost benefit analysis).

Table 3.1 shows the payback period for four scenarios. To yield a payback of less than 10 years it would appear that it is essential that the capital cost is reduced. However, this should be achievable so should not be a barrier to the adoption of the SUSTRAIL vehicle in the industry.

Access charge discount	Discount rate	Capital Cost (relative to benchmark vehicle)	Payback period (years)
No	3%	175%	23
Yes	3%	175%	18
Yes	3%	137.5%	5
Yes	7%	137.5%	7

Table 3.1: Payback period for the SUSTRAIL vehicle under various scenarios

Assuming that the costs of ownership can be spread evenly over time using financial instruments, the impacts on freight operators' costs from introduction of the SUSTRAIL vehicle are shown in Figure 3.2. The higher ownership cost of the SUSTRAIL vehicles is more than offset by the savings in vehicle maintenance costs, and in addition there is a substantial gain from reduced track access charges. All of these net benefits are to intermodal freight operators in this scenario.

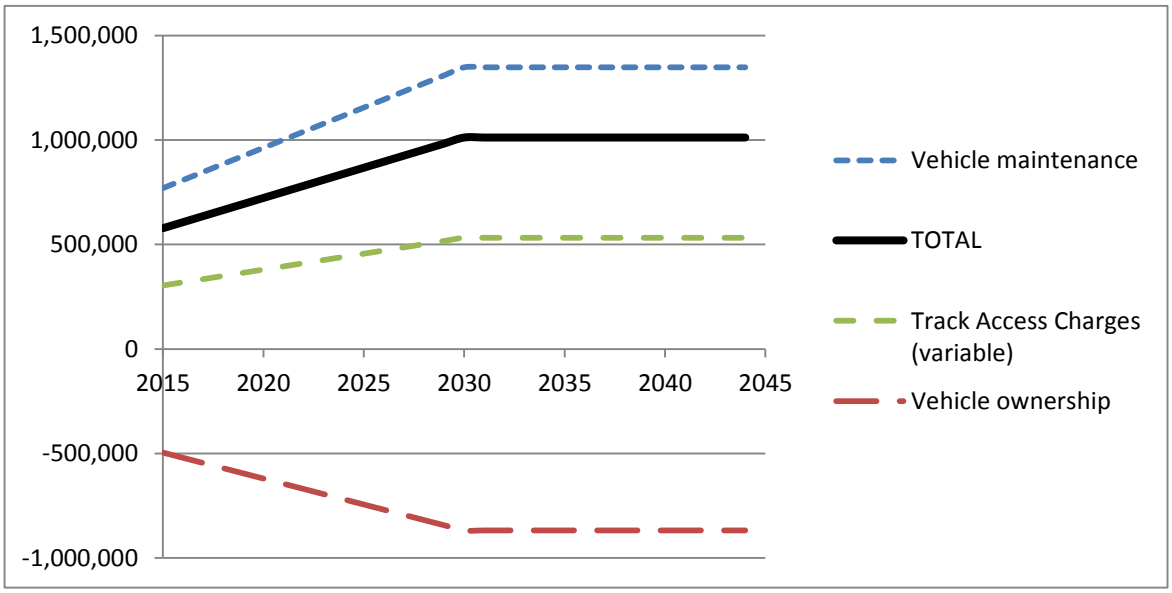


Figure 3.2: Cost savings to intermodal freight operators, SUSTRAIL0, UK route, £ per annum (2015 prices)

The implementation research (Chapter 5) finds that the SUSTRAIL innovations can be brought to market within 3 years; thereafter, as the existing wagon fleet is replaced with SUSTRAIL-type wagons the benefits will converge to those in the SUSTRAIL0 scenario above, whilst growth in the wagon fleet could be covered entirely by the novel wagons. Assuming an S-shaped adoption curve beginning in 2018 for the current fleet, we think a conservative estimate is that two-thirds of the total benefits shown above could be obtained over the 30 year period.

Assuming a 7% real discount rate for the freight operators, equivalent to a 9% nominal interest rate on the freight operator's funding offset by 2% general price inflation, there is a strong bias towards benefits early in the 30 year period. Taking this into account, approximately 20% of the benefits shown in Figure 3.2 should be achievable. That is, about £5.4million over the 30 year period (PV@7%), based on the UK Case Study parameters.

The Bulgarian Case Study found a negative benefit to the Freight Operators, however this is partly a reflection of the Track Access Charging assumptions used: whereas Track Access Charge savings made up just under half the benefits of SUSTRAIL0 in the UK Case Study, in Bulgaria this effect was very small indeed (D5.2, Appendix 3, Table 5.21). The Spanish Case Study results for freight operators are not straightforward to interpret on a € basis.

3.2.3 Impact on End Users

The Financial impact on End Users is dependent on the assumptions made about the Freight Operators' pricing behaviour. Two alternative assumptions were modelled:

i. The Freight Operator passes through 100% of the cost savings it receives to its customers. This assumption is useful to understand the maximum benefit the End Users might receive, but is unrealistic in that it leaves the Freight Operator with no commercial incentive to adopt the SUSTRAIL innovations. It should be treated as a limiting case.
ii. The Freight Operator passes through 50% of its cost savings to End Users for the first 10 years, thereafter 100%. This was judged to give the Freight Operator a more realistic incentive to adopt the SUSTRAIL innovations.

Assumption	**% reduction in the cost of Freight Service to End Users**	**End Users' Financial Benefit, PV@4%, £million (2015 prices)**
i. 100% of cost savings passed through	1.8%	12.7
ii. 50% of cost savings passed through for 10 years, thereafter 100%	0.9% (1.8%)	10.0

Table 3.2: End users' financial benefit from the SUSTRAIL vehicle under different assumptions, UK route

Under assumption (i) or (ii), therefore, the End Users stand to receive a substantial financial gain from the introduction of the SUSTRAIL vehicles. Again, the gradual implementation of the SUSTRAIL vehicles is likely to reduce these benefits by roughly one third.

3.3 Results for SUSTRAIL Vehicle and Track

3.3.1 Impact on the Infrastructure Manager

Introduction of the SUSTRAIL vehicles and SUSTRAIL track creates a larger stream of net benefits for the IM than the SUSTRAIL vehicles alone, as a result of additional savings in track maintenance and renewal costs from installation of premium rail steel. The total savings amount to a potential **10.1% reduction overall in track maintenance and renewal costs**, if the whole intermodal fleet were to shift to SUSTRAIL vehicles.

For the UK Case Study, this equates to a potential £39million cost saving to the IM (PV@4% over 30 years). The Bulgarian Case Study figures are again much larger, reflecting the volume of rail freight traffic and the distances involved (€2.7billion @3%). The Spanish Case Study results imply a €36million cost saving to the IM (@4%).

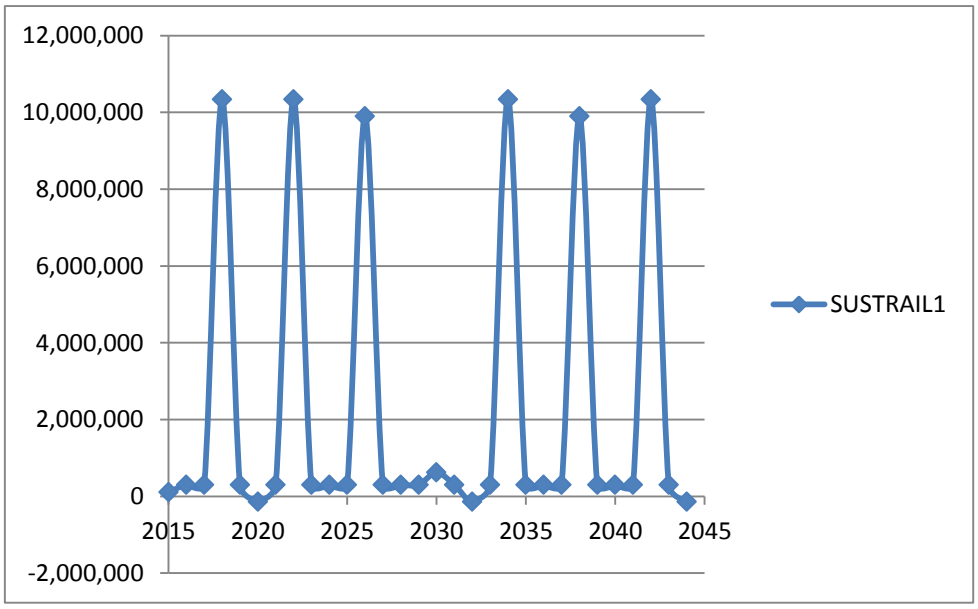


Figure 3.3: Track maintenance and renewal cost savings (cash flow), SUSTRAIL1, UK route, £ (2015 prices)

3.3.2 Impact on the Freight Operators

As with SUSTRAIL0, the direct impact of SUSTRAIL1 is an **11.8% reduction in intermodal wagon ownership and maintenance costs**, however we now expect to see a **17.4% reduction in Track Access Charges to intermodal wagons** and a **6.9% reduction in Track Access Charges to other wagons and locos**.

Figure 3.4 shows the impacts on intermodal freight operators' costs from introduction of the SUSTRAIL vehicle and track. Again, we anticipate the gradual implementation of the SUSTRAIL innovations across the route. If we phase the track innovations in at the same rate as the wagon innovations, and apply a 7% discount rate, we obtain a positive net benefit of £7.7million over the 30 year period (PV@7%), based on the UK Case Study parameters. We can add to this another £0.5million (PV@7%) for the benefits to non-intermodal freight, which also receives a Track Access Charge reduction due to premium rail steel.

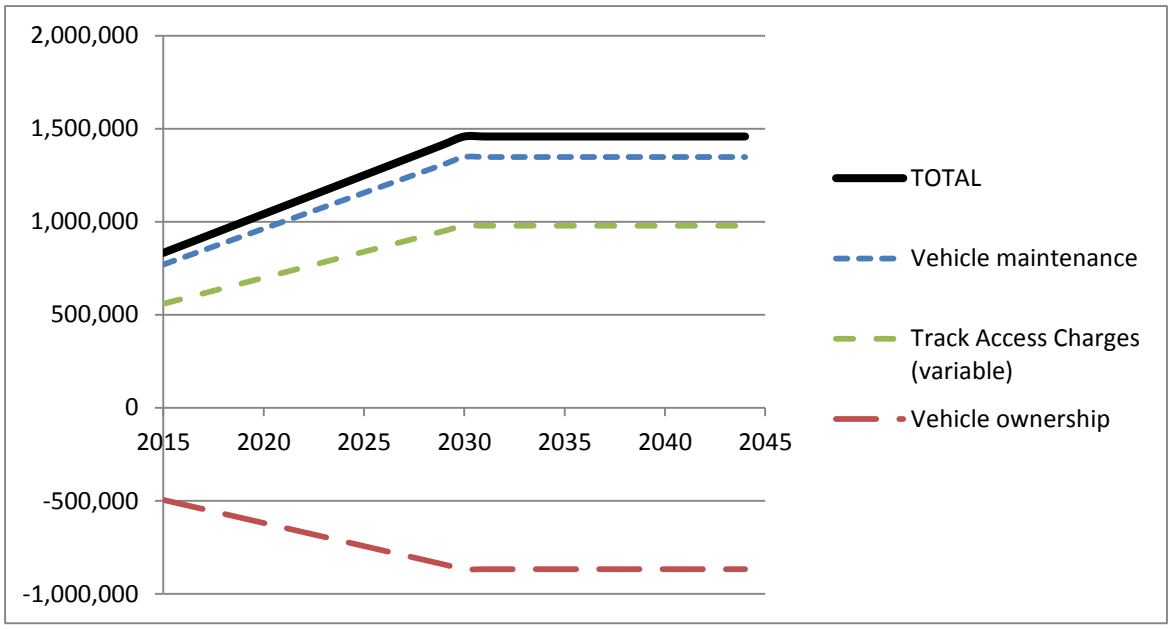


Figure 3.4: Cost savings to intermodal freight operators, SUSTRAIL1, UK route, £ per annum (2015 prices)

In the Bulgarian Case Study, SUSTRAIL1 yields a small positive net benefit to the freight operator (€1.0million, PV@7%).

3.3.3 Impact on End Users

The Financial impact on End Users under the two alternative assumptions given above, is shown in Table 3.3.

Assumption	**End Users' Financial Benefit, PV@4%, £million (2015 prices)**	
	intermodal	**non-intermodal**
i. 100% of cost savings passed through	17.3	1.4
ii. 50% of cost savings passed through for 10 years, thereafter 100%	13.5	1.1

Table 3.3: End users' financial benefit from the SUSTRAIL vehicle+track under different assumptions, UK route

Under assumption (i) or (ii), therefore, the End Users stand to receive a substantial financial gain from the introduction of the SUSTRAIL vehicles. Again, the gradual implementation of the SUSTRAIL vehicles is likely to reduce these benefits by roughly one third.

3.4 Results for SUSTRAIL Vehicle and Track operating at higher speed

3.4.1 Impact on the Infrastructure Manager

Introducing the SUSTRAIL vehicles and SUSTRAIL track while simultaneously increasing the maximum speed of freight operation from 120kph to 140kph, creates total savings to the IM equal to **7.5% reduction overall in track maintenance and renewal costs** at route level. This assumes that all intermodal traffic is able to travel at the higher maximum speed (i.e. the SUSTRAIL vehicles). There are additional benefits from the release of capacity – see §4.3.

For the UK Case Study, this equates to a potential £29million cost saving to the IM (PV@4% over 30 years). The Bulgarian Case Study figures are again much larger, reflecting the volume of rail freight traffic and the distances involved (€1.6billion @3%). The Spanish case study finds little difference from the 'SUSTRAIL1' scenario, as the route is already cleared to a high speed – i.e. the savings to the IM should be in the region of €36million (@4%).

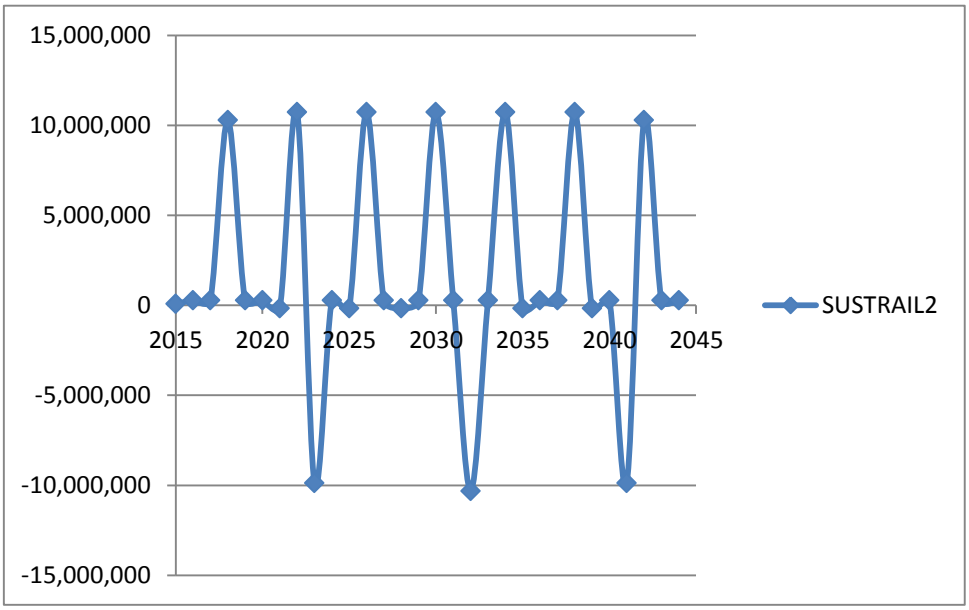


Figure 3.5: Track maintenance and renewal cost savings (cash flow), SUSTRAIL2, UK route, £ (2015 prices)

3.4.2 Impact on the Freight Operators

The impact on Freight Operators is made more complex by the increased fuel consumption (3.7%) caused by the higher-speed running in SUSTRAIL2. Overall, we expect a **9.7% reduction in intermodal wagon ownership and maintenance costs**, a **3.7% increase in fuel costs,** a **15.2% reduction in Track Access Charges to intermodal wagons** and a **4.8% reduction in Track Access Charges to other wagons and locos**.

Figure 3.6 illustrates this. Again, if we phase the track innovations in at the same rate as the wagon innovations, and apply a 7% discount rate, we obtain a positive net benefit of £1.6million over the 30 year period (PV@7%), based on the UK Case Study parameters. We can add to this another £0.3million (PV@7%) for the benefits to non-intermodal freight, which also receives a Track Access Charge reduction due to premium rail steel.

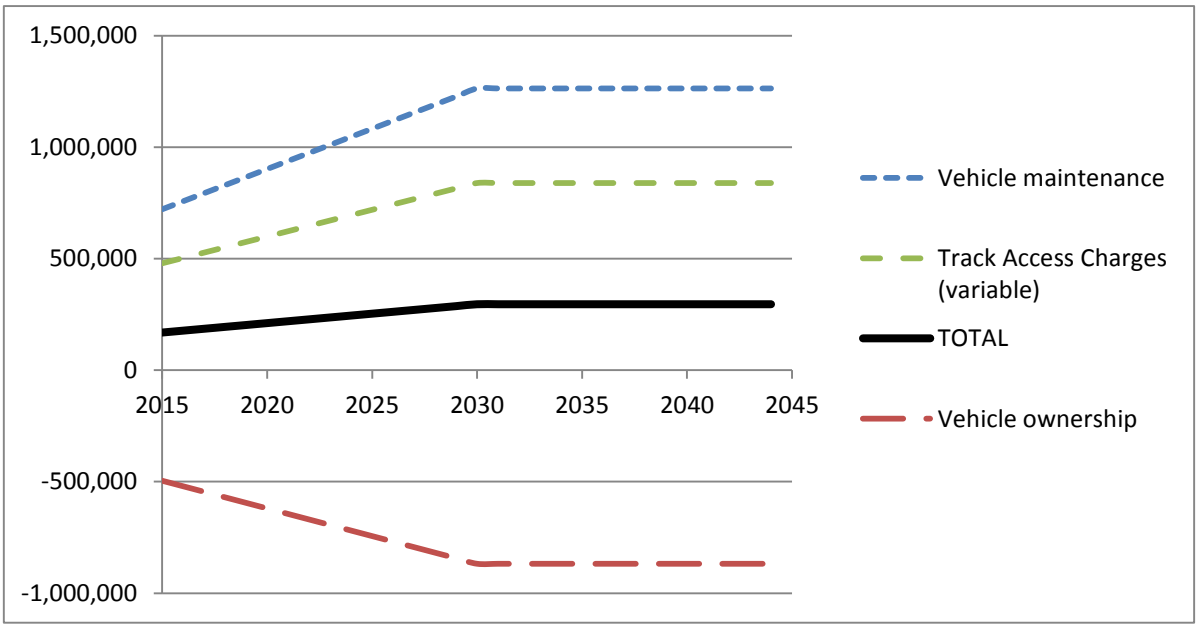


Figure 3.6: Cost savings to intermodal freight operators, SUSTRAIL2, UK route, £ per annum (2015 prices)

In the Bulgarian Case Study, SUSTRAIL2 yields a small negative net benefit to the freight operator (€-0.6million, PV@7%).

3.4.3 Impact on End Users

The Financial impact on End Users under the two alternative assumptions given above, is shown in Table 3.4.

Assumption	**End Users' Financial Benefit, PV@4%, £million (2015 prices)**	
	intermodal	**non-intermodal**
i. 100% of cost savings passed through	0.4	0.9
ii. 50% of cost savings passed through for 10 years, thereafter 100%	0.0	0.7

Table 3.4: End users' financial benefit from the SUSTRAIL vehicle+track with increased freight speed, under different assumptions, UK route

Under assumption (i) or (ii), therefore, the End Users stand to receive a small financial gain from the introduction of the SUSTRAIL vehicles. The implications for intermodal freight need to be managed carefully if 50% of costs are passed through, since there could be a very small negative impact to freight operators – in practice, freight operators would pass on less of their savings to maintain their profitability, unless there was competitive pressure to do so. Again, the gradual implementation of the SUSTRAIL vehicles is likely to reduce these benefits by roughly one third.

4. THE SOCIO-ECONOMIC BUSINESS CASE

4.1 Outline of the analysis

The socio-economic cost-benefit analysis is distinguished by:

- the inclusion of all costs and benefits, whether financial or not – non-financial impacts are valued using evidence gathered at the European and national levels, e.g. Ricardo-AEA (2014) and DfT (2014). D5.2 (Nellthorp et al, 2015) contains more extensive descriptions of the methods and values used;
- the use of a social discount rate rather than a commercial rate – by default we use the 4% rate required by the EU Impact Assessment Guidelines 2009 (SEC(2009)92);
- the calculation of an overall social Net Present Value (NPV) across all groups, providing an indicator of the economic worth of each SUSTRAIL package (0,1&2).

4.2 Results

The results of the socio-economic cost-benefit analysis are shown in Table 4.2 overleaf. This demonstrates that the SUSTRAIL innovations are beneficial in terms of their overall social Net Present Value (NPV). When applied to an example mixed-use rail corridor in the UK, we find that the Social NPVs of each option are:

- SUSTRAIL0 (vehicles only): + €22 million
- SUSTRAIL1 (vehicles and track): + €76 million
- SUSTRAIL2 (vehicles and track, enhanced speed): + €57 million

This indicates that SUSTRAIL1 is the option with the greatest economic worth. This ranking of the three options is also consistent with the Bulgarian Case Study example (Table 4.1). It also corresponds well to the findings in the Financial Case which indicated that SUSTRAIL1 is likely to be the preferred scenario for each group: IMs; freight operators; and end users.

Economic indicator	Variant		
	SUSTRAIL 0	SUSTRAIL 1	SUSTRAIL 2
Economic NPV, €	-295,802,852	654,960,312	375,301,588

Table 4.1: Summary results of the socio-economic cost-benefit analysis, SUSTRAIL0,1&2, BG route

Also important is the finding, from Table 4.2, that for each impact group (the IM, the freight operator, the end users and 3rd parties) the net impact is positive. SUSTRAIL can be seen as a win-win intervention, with the main caveats being that:

- SUSTRAIL0 has zero impact on the IM, on non-intermodal freight operators and non-intermodal end users – this makes it more difficult to incentivise these parties to support the intervention, and conversely helps make the case for packaging the SUSTRAIL wagon with the track, in order to ensure all parties have a motive for signing-up.
- There are clearly some differences between the UK, Bulgarian and Spanish cases studied, in this respect. When applying the SUSTRAIL innovations in EU-wide or country specific applications, care should be taken to check the which of the three case studies is most similar to the sector under investigation: SUSTRAIL improvements in the context of a steadily-growing freight railway (~4% per annum) are represented by the UK; SUSTRAIL improvements as part of a transformative change in speeds and

capacity is best represented by the Bulgarian case study; whilst a case with much potential but also some barriers to implementation is the Spanish Case Study, where gauge, unbalanced flows and track layout/hilliness issues are impediments to the economic case for SUSTRAIL.

4.3 Results

			Net Present Value (NPV) @4% for each scenario, €		
			SUSTRAIL0	SUSTRAIL1	SUSTRAIL2
Impact Groups		***Impacts***	(vehicle only)		(140kph)
Infrastructure Manager (IM)	ΔCosts	Track investment	0	-260,777	-260,777
		Track renewals	4,586,538	45,007,611	32,798,176
		Track maintenance - preventive	805,699	6,159,712	5,011,935
		Track maintenance - corrective	1,893,713	1,893,713	1,183,570
		SubTOTAL	7,285,950	52,800,260	38,732,906
	ΔRevenues	Track access charges - intermodal	-7,285,950	-13,394,433	-11,491,462
		Track access charges - other	0	-1,808,674	-1,244,443
		SubTOTAL	-7,285,950	-15,203,107	-12,735,905
	Net Benefit	**SubTOTAL**	**0**	**37,597,153**	**25,997,000**
Freight Operators (FOCs) - intermodal	ΔCosts	Vehicle maintenance costs	27,127,156	27,127,156	25,427,062
		Vehicle ownership costs	-17,471,655	-17,471,655	-17,471,655
		Freight operators' fuel costs	0	0	-18,896,672
		Other operating costs	0	0	0
		Track Access Charges (variable)	7,285,950	13,394,433	11,491,462
		SubTOTAL	16,941,451	23,049,934	550,197
	ΔRevenues	Freight service charges (money)	-13,370,069	-18,045,948	34,195
	Net Benefit	**SubTOTAL**	**3,571,382**	**5,003,986**	**584,392**
Freight Operators (FOCs) - other	ΔCosts	Track Access Charges (variable)	0	1,808,674	1,244,443
		SubTOTAL	0	1,808,674	1,244,443
	ΔRevenues	Freight service charges (money)	0	-1,515,444	-952,588
	Net Benefit	**SubTOTAL**	**0**	**293,230**	**291,855**
End Users - intermodal	ΔUser Benefits	- reduced freight cost	13,370,069	18,045,948	-34,195
		- reliability	4,050,831	6,652,993	4,284,235
		- time savings	0	0	17,924,567
	Net Benefit	**SubTOTAL**	**17,420,901**	**24,698,941**	**22,174,606**
End Users - other	ΔUser Benefits	- reduced freight cost	0	1,515,444	952,587
		- reliability	0	563,946	377,920
		- time savings	0	0	0
	Net Benefit	**SubTOTAL**	**0**	**2,079,390**	**1,330,507**
3rd Parties	ΔBenefits	CO_2 reduction	703,079	4,278,505	4,721,968
		Air pollution reduction	-9,197	2,145,416	1,688,424
		Noise reduction	1,277,439	1,647,927	1,473,094
	Net Benefit	**SubTOTAL**	**693,882**	**6,423,921**	**6,410,392**
Social Net Present Value (NPV)		**TOTAL**	**21,686,165**	**76,096,621**	**56,788,754**

Table 4.2: Results of the socio-economic cost-benefit analysis, SUSTRAIL0,1&2, UK route

Finally, an important additional result comes from the Path Capacity Benefits research conducted in Task 5.2.3 and reported in D5.2, Section 7. It was found that a value of £14 per path km could be justified for a fully utilised path. In practice, paths created are unlikely to exactly match the demands of a passenger operator: an additional service may require more

than one standard slot per train; also most freight trains are not daily, so the value of slots made available is reduced. In the context of a mixed-use intermodal corridor, it was judged reasonable to assume slots freed-up are able to be used productively on 50% of occasions. Further assuming the one path per direction per day is created in the UK Case Study, this leads to a Present Value of Path Capacity Benefits of €31.4million (2015 prices, 4% discount rate) for the UK Case Study only. Hence on a relatively congested mixed-use line, it is conceivable that the Path Capacity Benefits might shift the advantage from SUSTRAIL1 (at conventional freight speeds) to SUSTRAIL2 (140 vs 120kph maximum freight speed). It is not expected that these benefits would arise on the Bulgarian or Spanish Case Study corridors.

5. IMPLEMENTATION OF THE SUSTRAIL INNOVATIONS

Innovations cannot be considered to be useful if they are not implemented. The wide range of innovations considered within the SUSTRAIL project all have potential benefits, but this alone will not necessarily mean they will be taken up by the rail industry. It is important within the project to consider the barriers to their implementation and demonstrate reasons to adopt them.

5.1 Technical Implementation

Railways have been established across Europe for over 100 years, during this time continuous improvement has resulted in an evolving system that requires careful consideration for the introduction of new technology and processes to ensure they are compatible with the existing environment. This aspect is considered for all the SUSTRAIL innovations as their introduction will be progressive and will therefore run alongside the existing systems that they will ultimately replace. A good example of this is the service life of wagons; since this is approximately 35 years or longer, conventional wagons and SUSTRAIL wagons will operate alongside each other for many years.

This section considers the feasibility of the innovations being developed into a useable product and the steps required to do so, such as product approval and testing etc. It will also consider phasing issues and dependencies.

It is important to identify the key beneficiary of a given innovation as knowing the issues they face will enable us to fully consider the implementation barriers. A good example of this would be improved vehicle suspension, which makes the vehicle initially more expensive to buy, but this is offset by reduced track damage which could in turn lead to reduced track access charges for the vehicle operator. Purchase price, maintenance, and operating costs are all of course key decision points for any product, but reliability is key to avoid unexpected issues. Legislation and standards can also play a key role in driving the adoption of new technology.

Each innovation has been considered by the appropriate project partner for the following criteria:-

- Innovation opportunity / need
- Next development steps / deployment
- Issues and dependencies

Table 5.1 summarises the technical implementation issues surrounding the vehicle innovations. Disc brakes are the only Work Package 3 innovation that is available in 2015 as they have a manufacturer or supplier already in place for various passenger train and locomotive applications; the others are not commercially available so dates have been predicted. These are based upon the time to complete the next development phases and include time for certification / approvals. However, they should be considered as the earliest possible dates for implementation. The SUSTRAIL innovation owners will pursue future development opportunities.

To help identify the potential size of the market for the SUSTRAIL wagon, information was gathered on the number of intermodal wagons that are on the UK network. Research suggests

there are more than 4000 British Railways era wagons plus in excess of 4000 newer ones, giving a minimum total of approximately 8000 units in total. Information published by Freightliner (UK Freight Company) states that the current average life span for a wagon is 35 years; this would suggest a replacement rate of around 214 wagons per year for the UK alone at the current market share for rail freight. However, the rail industry across Europe has plans to increase market share considerably from current levels, for example in the UK the "Value and Importance of Rail Freight" report published by Network Rail anticipates "freight demand to grow by at least 30% over the next decade; the equivalent of 240 additional freight trains a day, and by as much as 140% over the next 30 years".

This would result in a significant increase in the numbers of wagons in service over the next 20 to 30 years. When this market share increase is considered along with the number of market countries, then the business opportunity for wagon makers to produce a SUSTRAIL type of vehicle is attractive and should in turn produce a vehicle at much more competitive prices due to high potential unit numbers. This would, in turn, reduce the payback period and drive increased implementation. The technology introduced in the SUSTRAIL intermodal vehicle could also be introduced to other wagon types, perhaps via modularised components such as replacement bogies.

Innovation	Beneficiary	Implementation Timing	Dependencies
Vehicle: Novel running gear	Vehicle Operator	Predicted 2017	New bogie required to accommodate the novel suspension. Prototype testing to be concluded with development to final product.
Vehicle: Axle mounted disc brakes	Vehicle Operator & Infrastructure Manager	Available 2015	New bogie required to accommodate the revised braking system. Training for maintenance techniques and local certification if required. This may be restricted for use only for wholly disc brake equipped trains.
Vehicle: On-board axle box temperature monitoring	Vehicle Operator	Predicted 2017	Power supply and communication to be included in future development. Prototype testing to be concluded with development to final product.
Vehicle: Spring inserts for reduction of structure-borne noise emissions	Vehicle Operator & Infrastructure Manager	Predicted 2016	Known technology for passenger train application. Prototype testing to be concluded with development to final product.
Vehicle: Axle Coating	Vehicle Operator & Owner	Predicted 2016	Development of non-destructive testing process required with associated training and local certification if required.
Vehicle: Wagon wheel set	Vehicle Operator	Predicted 2018	Prototype testing to be concluded with development to final product.
Vehicle: Friction modifiers	Vehicle Operator & Owner	Predicted 2017	Friction modifier testing to be concluded with development of dispensing system.
Vehicle: Aerodynamic fairings	Vehicle Operator	Predicted 2016	Prototype testing to be concluded with development to final product.

Table 5.1: Vehicle innovations

The infrastructure innovations are considered in Table 5.2. All are considered suitable for implementation, although a number will require further development. None of these infrastructure innovations have any dependencies that would prevent introduction individually as soon as they are ready and they do not have any interface issues with existing infrastructure. A good example of this is Premium Rail Steel; there are already multiple materials in use for rail and joining these materials together is included in the development process. The key barriers to implementation are generally the development of maintenance and inspection techniques, training packages and approval/certification.

Innovation	Beneficiary	Implementation Timing	Dependencies
RAIL: Premium rail steel (plain line)	Infrastructure Manager	Available 2015	Training for welding techniques and local certification if required.
RAIL: Premium rail steel (S&C)	Infrastructure Manager	Available late-2015	Development of welding repair techniques and local certification if required.
RAIL: Fatigue life prediction	Infrastructure Manager	Predicted for 2018	Further development of model and verification required.
RAIL: Effect on track forces by changing rail profile	Infrastructure Manager	Predicted for 2016	Training for welding techniques and local certification if required.
EARTHWORKS: sensor in geo-textiles	Infrastructure Manager	Available late-2015	Installation of the sensor-embedded geo-grids requires extra care compared to normal geo-grids in order to prevent failure of the optical fibre
RAIL: Impact of inspection and monitoring technologies (with MerMec).	Infrastructure Manager & Train Operator	Available 2015	Development of alarm settings for specific vehicles and routes.
RAIL: Switch lubrication testing	Infrastructure Manager	Available 2016	Environment testing facility to be procured to extend testing temperature range (2016 on)
RAIL: Smart Washer	Infrastructure Manager	Predicted 2018	Prototype testing to be concluded with development to final product.
RAIL: Rail Fastening Device	Infrastructure Manager	Predicted 2017	Prototype testing to be concluded with development to final product.

Table 5.2: Infrastructure innovations

5.2 Human Factor issues

In addition to the technical issues, a further set of work was to assess and quantify how much the SUSTRAIL innovations impact on the rail transport industry in terms of personnel needs. This is necessary in order to establish if the project is convenient and desirable for the society as a whole.

The analysis of phasing issues of SUSTRAIL innovations on vehicles and tracks is built through the definition of a business model and the assessment of impacts. One particular aspect includes the identification and the assessment of human factor issues, such as:

- the impacts of SUSTRAIL innovations on vehicles and tracks on human aspects of the rail freight operations, (maintenance, inspection and other train handover activities)
- key barriers for implementation of the designed innovations that may be brought by human factors during the phasing of the introduction of innovations

The analysis was developed in two steps. The first step of the process was completed during 2013, and consisted, after a literature review, in a first round of interviews, discussing with relevant stakeholders the possible impacts of a provisional list of innovations. This permitted researchers to elaborate a final list of questions and to calibrate the interviews in order to produce relevant results in the general context of the project. It was agreed to focus the interviews on two main innovations on vehicles and tracks that are close to being realised in the final phase of the project.

Some activities and dimensions are more affected by the SUSTRAIL innovations than others: maintenance activities (rail replacement, track inspections, transition management, ballast screening, tamping etc.); inspections (time needed for inspections, and personnel needs); ergonomics of the maintenance agents (e.g. working positions, hot/cold conditions, dangerous locations), and the skills of the agents with consequent training required. This list represents the starting point for the analysis of the human factors variations determined by the implementation of the SUSTRAIL innovations.

The outcome of the interviews gave useful provisional insights on the impacts of SUSTRAIL innovations on human factors. In particular, **the effort for maintenance and inspection will decrease**, but it is not possible to quantify or to assess homogeneously the magnitude. The results of the interviews reflect the expectation of a **decrease in track and vehicle maintenance efforts**. In fact, this area is expected to benefit most from SUSTRAIL innovations in terms of a **decrease in human factor related costs**. **Regarding track maintenance activities, cost decreases are expected for several tasks due to a decrease in the frequency and an increase in automation. In general, manual work tasks are expected to decrease due to the implementation of SUSTRAIL innovations, in particular the need for walking along tracks.** For several track and vehicle inspection and maintenance tasks, the experts expect a change in demand for the handling of machinery and for different skill sets to be required, such as an **increase in engineering and technical skills, and skills associated with computer and digital systems**; training activities to accompany the introduction of SUSTRAIL innovations are expected to be needed.

As an example of the output, the following images summarize the main results of the questionnaire for the premium rail steel. It has to be underlined that results are adjusted in order to show the main output of the questionnaire. If there was no unequivocal output the result followed the majority.

Maintenability	**Frequency**	**Automation**	**Costs**		
	Decreased	Unchanged	Decreased		
	3	1	2		
Inspectability	**Safety**	**Efficiency**	**Costs**	**Frequency**	**Time**
	Unchanged	Unchanged	Unchanged	Unchanged	Unchanged
	2	2	2	2	3
Accessibility	**Efficiency**	**Costs**			
	Unchanged	Unchanged			
	3	2			
Ergonomic	**Working position**	**Dangerous Location**			
	Unchanged	Unchanged			
	3	3			
Handling of maintenance tools	**New Tools**	**New Machinery**			
	Unchanged	Unchanged			
	3	3			
Skills	**Training**	**New Personnel**	**Qualifications**	**Costs**	
	Increased	Unchanged	Increased	Unchanged	
	2	1	3	1	
Maintenance strategy	**Frequency**	**Costs**	**New Planing**		
	Unchanged	Unchanged	Unchanged		
	1	1	2		
Safety	**Global safety**	**Accidents**	**Delays**	**Health conditions**	**Operational efficiency**
	Increased	Decreased	Decreased	Unchanged	Unchanged
	2	2	2	2	2

Table 5.3: Premium Rail Steel -intensity of the results

Maintenability	**Frequency**	**Automation**	**Costs**		
	Decreased	Unchanged	Decreased		
Inspectability	**Safety**	**Efficiency**	**Costs**	**Frequency**	**Time**
	Unchanged	Unchanged	Unchanged	Unchanged	Unchanged
Accessibility	**Efficiency**	**Costs**			
	Unchanged	Unchanged			
Ergonomic	**Working position**	**Dangerous Location**			
	Unchanged	Unchanged			
Handling of maintenance tools	**New Tools**	**New Machinery**			
	Unchanged	Unchanged			
Skills	**Training**	**New Personnel**	**Qualifications**	**Costs**	
	Increased	Unchanged	Increased	Unchanged	
Maintenance strategy	**Frequency**	**Costs**	**New Planing**		
	Unchanged	Unchanged	Unchanged		
Safety	**Global safety**	**Accidents**	**Delays**	**Health conditions**	**Operational efficiency**
	Increased	Decreased	Decreased	Unchanged	Unchanged

Table 5.4: Premium Rail Steel-main results

6. CONCLUSIONS

In conclusion, the SUSTRAIL research has investigated a wide set of vehicle and track technologies (WP3&4), in search of a package of innovations which together meet the goals of the project: to attract freight towards rail from less sustainable modes (road in particular) by designing a freight vehicle-track system offering higher speed and improved availability at reduced cost; and increasing the sustainability of rail freight, both in environmental and economic terms – for example by reducing noise per tonne-km and improving cost-competitiveness with road freight. The process of narrowing-down a long list of innovations and ultimately demonstrating the value of the chosen package of innovations has been the task of the Business Case. This deliverable summarises the final Business Case. It concludes a series of deliverables that examined the Life Cycle Cost (LCC) and Reliability, Availability, Maintainability and Safety (RAMS) performance of the innovations (D5.1); the end user and environmental benefits (D5.2); the track access charging aspects (D5.3); technical implementation (D5.4) and human factors (D5.7).

The Duty Requirements for the SUSTRAIL innovations were agreed early on (§2.2). Highest priority was given to:

- a modest increase in freight speed (120 to 140kph UK; 100 to 120kph elsewhere) – in order to open up potentially-valuable additional paths on more congested networks;
- optimisation of axle loads – trading-off payload against speed and track damage;
- targeting a reduction in vehicle mass and energy required (20%) – in practice this was traded against an increase in the mass of the disc braking system, which enabled other duty requirements to be met; and
- reduction in track forces (lateral and vertical) through improved bogie design.

Other medium and lower priority duty requirements were listed in §2.2.

A further selection process was undertaken for vehicle innovations (WP3) and separately for track innovations (WP4) taking into account the Business Case framework (§2.3). .

The emerging package of innovations was subjected to LCC and RAMS analysis, whose principal findings were that both the wagon and the track innovations produce savings in life-cycle cost and improvements in availability and mission success measures for rail freight (§2.4).

The LCC and RAMS models were focused on a relatively small part of the rail freight cost base, so work was required in Task 5.2 to aggregate up to track maintenance costs and freight operators' costs, in order to estimate the demand impacts and user benefits. Aggregation was undertaken to provide results at the Case Study route level (§2.5).

Further essential enabling work was carried out to:

- model freight demand in the three Case Studies (mixed-use corridors in the UK, Bulgaria and Spain), estimate the user benefits and the environmental impacts and benefits (§2.6);
- analyse track access charging regimes in place in the EU with a view to making recommendations on how to distribute the whole-system savings achieved by the SUSTRAIL innovations, to the benefit of all parties (§2.7);
- examine implementation issues and opportunities, including timescales to deployment of the technologies chosen for the SUSTRAIL vehicle and track (§2.8).

All of the above was reported in detail in deliverables D5.1-5 and 5.7.

The main findings of the Final Business Case, which are the main subject of this deliverable, are as follows.

The vehicle and track innovations selected are as set out in §2.3. Their purpose, taken together as a package, is:

- to reduce track damage at a given speed and axle-load for intermodal and similar trains;
- to allow a modest increase in maximum freight train running speeds, in order to mix better with other traffic improving reliability, and opening up additional paths on more congested lines;
- to extend the interval for track renewal and maintenance activities through both improved track and track-friendly vehicles;
- to use technology to cut down vehicle and track maintenance activities – for example by using condition monitoring to reduce failures and corrective maintenance costs, and by optimising the design of system components, thereby reducing the life-cycle costs of wagons and track, helping to make rail freight more cost-competitive;
- to improve availability and so help to reduce fleet costs for freight wagons;
- to reduce noise through the use of disc brakes instead of conventional tread brakes;
- by competing more strongly with road freight, to achieve reductions in CO_2 and local air pollutant emissions at the level of the European freight system.

The final outcomes of these various – mostly complementary – effects are best summarised in the socio-economic cost-benefit analysis of the SUSTRAIL innovations (Table 4.2). This shows that: (i) SUSTRAIL can be seen as a win-win intervention – for each impact group (the IM, the freight operator, the end users and 3rd parties) the net impact is positive for the SUSTRAIL package as a whole; (ii) the SUSTRAIL innovations are beneficial in terms of their overall social Net Present Value (NPV), whichever package is chosen (vehicles only/vehicles+track/vehicles+track+enhanced speed); (iii) the package of vehicles+track appears to have the strongest case, across more than one Case Study; except that (iv) when Path Capacity Benefits are introduced, on a route that is already quite congested, such as the UK Felixstowe-Peterborough-Ipswich route, the net benefit of the enhanced speed package appears to overtake the standard SUSTRAIL vehicle+track package.

Alongside this, the Financial Business Case is the other key set of outcomes, and we found positive Net Present values for all industry parties for each of the packages. Further details are given in Chapter 3. The financial analysis demonstrates the inter-relatedness of the Track Access Charge assumptions and the financial outcomes by group, and shows that a reduction in Track Access Charges and a reduction in the capital cost of the SUSTRAIL vehicle are required in order to achieve a viable payback period (5-7 years) for the SUSTRAIL vehicle. The recommendations for adjustment of Track Access Charges to facilitate the deployment of more sustainable vehicles and track were set out in Chapter 2.

7. REFERENCES

[1] Beagles A, Bezin Y, Jablonski A, Nellthorp J and Wheat PE (2012), *SUSTRAIL D2.5*: *Holistic approach to the vehicle-track system*, SUSTRAIL project (The sustainable freight railway: Designing the freight vehicle – track system for higher delivered tonnage with improved availability at reduced cost), Grant Agreement n°: 265740 FP7 - THEME [SST.2010.5.2-2.]

[2] Iwnicki S et al (2015), *SUSTRAIL D3.7: A design guide for sustainable freight vehicles*, SUSTRAIL project (The sustainable freight railway: Designing the freight vehicle – track system for higher delivered tonnage with improved availability at reduced cost), Grant Agreement n°: 265740 FP7 - THEME [SST.2010.5.2-2.]

[3] Rantatalo, M., Famurewa, S. and Juntti, U. (2015), *SUSTRAIL D5.1 LCC and RAMS analysis*, SUSTRAIL (The sustainable freight railway: Designing the freight vehicle – track system for higher delivered tonnage with improved availability at reduced cost), EU 7th Framework Programme, Grant # 265740 FP7 - THEME [SST.2010.5.2-2.].

[4] Nellthorp et al (2015), *SUSTRAIL D5.2: Economic benefit final report*, SUSTRAIL (The sustainable freight railway: Designing the freight vehicle – track system for higher delivered tonnage with improved availability at reduced cost), EU 7th Framework Programme, Grant # 265740 FP7 - THEME [SST.2010.5.2-2.].

[5] Wheat, P., Smith, A. and Matthews, B. (2014), *SUSTRAIL D5.3: Access Charge Final Report*, SUSTRAIL (The sustainable freight railway: Designing the freight vehicle – track system for higher delivered tonnage with improved availability at reduced cost), EU 7th Framework Programme, Grant # 265740 FP7 - THEME [SST.2010.5.2-2.].

[6] Blacktop, K. et al (2014), *SUSTRAIL D5.4: Technical implementation and phasing issues*, SUSTRAIL (The sustainable freight railway: Designing the freight vehicle – track system for higher delivered tonnage with improved availability at reduced cost), EU 7th Framework Programme, Grant # 265740 FP7 - THEME [SST.2010.5.2-2.].

[7] Nellthorp, J. et al (2013), *SUSTRAIL D5.5: Interim Business Case Synthesis Report to Guide WP3 and WP4*, SUSTRAIL (The sustainable freight railway: Designing the freight vehicle – track system for higher delivered tonnage with improved availability at reduced cost), EU 7th Framework Programme, Grant # 265740 FP7 - THEME [SST.2010.5.2-2.].

[8] Milotti et al (2015), *SUSTRAIL D5.7: An impact analysis for operation of the optimised freight vehicle and track system*, SUSTRAIL (The sustainable freight railway: Designing the freight vehicle – track system for higher delivered tonnage with improved availability at reduced cost), EU 7th Framework Programme, Grant # 265740 FP7 - THEME [SST.2010.5.2-2.].